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Effect of Soil Reaction on the Efficiency of Various Phosphates for Cotton and on Loss of Phosphorus by Erosion[1]

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SOIL reaction is an important factor affecting the efficiency of various phosphates as a source of phosphorus for plant growth. It may be changed rather rapidly by the addition of lime, or it may be changed to a considerable extent by the continued use of certain kinds of nitrogen fertilizers.

The availability of native soil phosphorus in acid soils seems to increase with an increase in pH up to a certain point. Salter and Barnes (8)[3] studied the response of a number of crops to superphosphate at five different pH levels and found that with most crops nearly maximum yields were produced without phosphate fertilizer at pH 7.5, which was the most alkaline reaction studied. In a study of the calcareous soils of Idaho, Ensminger and Larson (3) reported that soils containing 0.5 to 1.0% calcium carbonate responded the least to phosphate fertilization. These soils had an average pH of 7.75. The effect of soil pH on the efficiency of added phosphorus varies with the source of material. Salter and Barnes (8) found that superphosphate ammoniated to 5 and 7% (nitrogen content) decreased in efficiency with increase in soil pH. Andrews (1) concluded that dicalcium phosphate was a good source of phosphorus in acid-forming fertilizers on acid soils but was a poor phosphorus source on soils high in lime. Also, he concluded that 3% ammoniated superphosphate was less valuable than superphosphate in acid-forming fertilizers, and was much less valuable in neutral fertilizers.

Investigations in recent years indicate a high loss of phosphorus by erosion. Scarseth and Chandler (9) reported that where superphosphate had been used for 26 years, 60% of the added phosphorus had been lost by erosion from a nearly level Norfolk loamy fine sand. Volk (11) found that 25% of the added phosphorus plus that orig-

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[3]Figures in parenthesis refer to "Literature Cited". p. 10.

inally in the soil had been lost by erosion from a Hartsells very fine sandy loam during a 14-year period of continuous cotton. Other investigators (2, 7) have reported nutrient losses by erosion.

The purpose of this paper is to report (a) the results of a field experiment on the effect of soil reaction on the efficiency of several sources of phosphorus; and (b) the results of laboratory studies on erosion losses of phosphorus and the forms of phosphorus in the soil as affected by soil reaction.

EXPERIMENTAL PROCEDURE

DESCRIPTION OF FIELD EXPERIMENT

The field experiment was started in 1930 on a nearly level Norfolk fine sandy loam at the Wiregrass Substation near Headland, Ala. This experiment was designed to study the effect of soil reaction on the efficiency of various sources of phosphorus for cotton production. There were two tiers each of 17 1/30-acre plots in duplicate. One tier was limed to approximately pH 6.5 at the beginning of the experiment, and the other tier was not limed. The untreated soil had a pH of 6.0. Fertilizer was applied annually at the rate of 600 pounds per acre of a 6–0–4 to the check plots and 600 pounds per acre of a 6–10–4 to the phosphated plots. The sources of phosphorus and nitrogen used are given in Table 1. One-fourth of the nitrogen was applied under the cotton and three-fourths as a side dressing. Muriate of potash was used as the soure of potash until 1943; sulfate of potash was used thereafter. Cotton was grown continuously for the 16-year period.

METHODS OF ANALYSES

All plots were sampled in 1929 before any treatments were made by taking 10 borings per plot of the surface soil. The plots were sampled again in November, 1945, at 0 to 8 inches and 8 to 16 inches depths. The surface samples consisted of 12 cores taken with a tube having a diameter of 1½ inches. Subsoil samples were taken from the same locations with a 1-inch auger. A tube was used for taking the surface sample instead of an auger, since its use made it possible to obtain a more representative subsoil sample. The samples were taken 6 to 8 inches from the cotton row, which means that the 1945 application of phosphate was not included in the sampling. A 2-mm. sieve was used in preparing the samples for analyses.

Total phosphorus was determined using the perchloric acid method of Sherman (10). Dilute acid-soluble phosphorus was run according to the modified Truog method (5). Ammonium fluoride-soluble phosphorus was run on a few samples by leaching 5 grams of soil with 250 ml of neutral 0.5N NH_4F solution. The pH determinations were made on a 1:1 soil water suspension using a glass electrode.

CALCULATION OF YIELD RESPONSE

As stated previously, each tier contained 17 plots in duplicate. Plots 1, 5, 9, 13, and 17 were laid out as check plots (no phosphorus plots), making a total of 10 check plots per tier. By assuming a uniform variation between check plots, a check yield was calculated for each treated plot. The increased yield for a particular treatment was then determined by subtracting the calculated check yield from the yield due to a certain treatment. All yield data reported are averages of duplicate plots.

RESULTS AND DISCUSSION

EFFECT OF SOIL TREATMENTS ON YIELD OF SEED COTTON

In Table 1 are given the yield of seed cotton for the check plots (no phosphorus plots) and the increased yields of seed cotton from the use of various sources of phosphorus. The results are given by 4-year

periods as well as for the 16-year period. On the plots receiving $NaNO_3$, either with or without lime, superphosphate gave the greatest increase in yield of seed cotton of any of the sources of phosphorus used. However, on plots receiving $(NH_4)_2SO_4$ this was not true. This would indicate a sulfur deficiency in the case of the $NaNO_3$ plots receiving phosphates other than superphosphate. The $NaNO_3$ plots did not receive any sulfur with the exception of the last three years when sulfate of potash was used as the source of potash for all plots instead of muriate of potash. Because of the apparent sulfur deficiency, the effect of soil raction changes produced by the use of $NaNO_3$ and $(NH_4)_2SO_4$ on the efficiency of the phosphates other than superphosphate cannot be properly evaluated. Also, the influence of lime on the effectiveness of the phosphates other than superphosphate cannot be determined in case of plots receiving $NaNO_3$. Superphosphate gave the greatest increase in yield of seed cotton on unlimed plots that received $NaNO_3$ and gave the smallest increase in yield on unlimed plots that received $(NH_4)_2SO_4$.

The effect of liming on the efficiency of these phosphates may be evaluated in case of the $(NH_4)_2SO_4$ plots. The average increased yield of seed cotton for the 16-year period was greater for each of the phosphates tested on the limed plots than on the unlimed plots. The increased efficiency of the phosphates as a result of liming was relatively greater for the last two 4-year periods than for the first two 4-year periods. Roberts, *et al.* (6), working with several Kentucky soils, reported that liming decreased the effectiveness of tricalcium phosphate on corn and wheat, but not on hay. On the other hand, liming increased the effectiveness of superphosphate, triple superphosphate, and dicalcium phosphate on corn and wheat, but the increase was rather small. The Kentucky workers found an appreciable increase in efficiency of all the phosphates on hay by liming.

The present yield data indicate a response to calcium supplied by the various phosphates. This is especially true for the unlimed tier where monocalcium, dicalcium, and tricalcium phosphates are used. These phosphates furnish calcium in increasing amounts in the order named, and in general the increased yield of seed cotton for the 16-year period is also in the same order. Since the solubility of these phosphates is in the reverse order, this response would appear to be due to calcium.

A comparison of the average check plot yields of the limed tier with the unlimed tier shows a response to lime. While the check plot yields for the first 4-year period were slightly higher on the unlimed tier than on the limed tier, the reverse was true for succeeding 4-year periods. The yield data for the last 4-year period show a difference of 115 pounds of seed cotton in favor of the limed check plots.

Monosodium and monoammonium phosphates were not satisfactory sources of phosphorus under most conditions of the experiment. They made the best showing when used on limed plots receiving $(NH_4)_2SO_4$. The data in Table 1 by 4-year periods show that these phosphates were the least efficient for the last 4-year period. Since there is a response to calcium, it is possible that the poorer showing

TABLE 1.—*Yield of seed cotton on check plots and increased yield over calculated check from various sources of phosphorus and nitrogen.*

Plot No.	Fertilizers used*		Tier 27, limed					Tier 28, unlimed				
	Source of phosphorus	Source of nitrogen	4-year av., 1930–33	4-year av., 1934–37	4-year av., 1938–41	4-year av., 1941–45	16-year av., 1930–45	4-year av., 1930–33	4-year av., 1934–37	4-year av., 1938–41	4-year av., 1942–45	16-year average 1930–45
1	Check	$NaNO_3$	1,041	1,229	944	919	—	1,097	1,170	847	849	—
2	Monosodium phosphate	$NaNO_3$	–42	19	106	1	21	–2	8	32	–36	0
3	Monocalcium phosphate	$NaNO_3$	–10	72	108	–12	39	2	80	96	118	74
4	Dicalcium phosphate	$NaNO_3$	38	–13	40	67	33	3	115	157	155	107
5	Check	$NaNO_3$	955	1,219	960	800	—	1,052	1,187	859	864	—
6	Tricalcium phosphate	$NaNO_3$	76	119	88	58	85	49	156	135	202	135
7	Superphosphate	$NaNO_3$	119	77	215	314	181	123	324	391	319	289
8	Monoammonium phosphate	$NaNO_3$	–9	28	–28	–76	–21	33	60	68	10	43
9	Check	$NaNO_3$	983	1,263	973	859	—	971	1,205	826	801	—
10	Monosodium phosphate	$(NH_4)_2SO_4$	137	169	207	161	168	115	241	84	–126	78
11	Monocalcium phosphate	$(NH_4)_2SO_4$	149	173	266	394	243	120	126	151	42	110
12	Dicalcium phosphate	$(NH_4)_2SO_4$	89	133	276	342	210	74	161	241	268	186
13	Check	$NaNO_3$	1,028	1,236	998	957	—	1,020	1,201	795	633	—
14	Tricalcium phosphate	$(NH_4)_2SO_4$	76	199	260	362	224	110	172	236	222	185
15	Superphosphate	$(NH_4)_2SO_4$	76	122	343	384	231	83	107	196	157	136
16	Monoammonium phosphate	$(NH_4)_2SO_4$	71	138	306	252	192	62	20	–201	–228	–87
17	Check	$NaNO_3$	1,033	1,232	892	947	—	980	1,199	854	756	—

*Check plots received 600 lbs. of 6–0–4 and all other plots received 600 lbs. of a 6–10–4, all annually. Muriate of potash was used as the source of potash until 1943 and K_2SO_4 since 1943.

of these phosphates may be due to the lack of calcium. Salter and Barnes (8) reported better utilization of monoammonium phosphate at neutral than at acid reactions.

LOSS OF APPLIED PHOSPHORUS

Soil samples collected at the beginning of the experiment and those collected 15 years later were analyzed for total phosphorus. The results are reported in Table 2. Phosphorus that could not be accounted for by analysis of the surface 16 inches of soil and by crop removal was assumed to be lost by erosion. The unlimed tier lost an average of 70% of the added phosphorus by erosion, and there was no difference between plots receiving $NaNO_3$ and those receiving $(NH_4)_2SO_4$. However, in case of the limed tier, the $NaNO_3$ plots lost an average of only 32% of the added phosphorus by erosion as compared with an average loss of 75% from the $(NH_4)_2SO_4$ plots. Even though the above figures are given as percentage of added phosphorus, it should be pointed out that native phosphorus as well as added phosphorus was lost by erosion. This fact is evident from the data given in Table 2. The unphosphated plots on the limed tier lost an average of 230 pounds per acre of P_2O_5 as compared to a loss of 291 pounds on the unlimed tier. However, in most cases the loss of phosphorus was much greater where phosphorus had been added.

The gain or loss of subsoil phosphorus cannot be accurately determined, since subsoil samples were not taken at the beginning of the experiment. The data in Table 2 on the gain or loss of subsoil phosphorus were obtained by subtracting the average total P_2O_5 content in the subsoil of the two closest check plots from the total P_2O_5 content in the subsoil of a phosphated plot. The limed plots receiving $NaNO_3$ show an average gain of 219 pounds per acre of P_2O_5 in the subsoil in contrast to an average gain of only 43 pounds where $(NH_4)_2SO_4$ was used. On the other hand, the $NaNO_3$ plots on the unlimed tier gained 16 pounds, while the $(NH_4)_2SO_4$ plots lost 31 pounds. Even though these may not be absolute values they do show appreciably greater movement of phosphorus into the subsoil as a result of applying lime and $NaNO_3$. Weiser (12), working with Addison clay in the laboratory, reported that $NaNO_3$ caused twice as much penetration of phosphorus as $(NH_4)_2SO_4$. Soil reaction apparently has influenced movement, since the data indicate more penetration in limed plots receiving $NaNO_3$ than in unlimed plots receiving $NaNO_3$.

SOLUBLE PHOSPHORUS AND pH VALUES

Dilute acid-soluble phosphorus (modified Truog method) and pH values are reported in Table 3. On the limed tier the pH of the surface soil of the $(NH_4)_2SO_4$ plots was about 0.7 of a unit lower than the $NaNO_3$ plots, while on the unlimed tier the difference was about 0.9 unit. On both tiers the pH of the subsoil samples from the $(NH_4)_2SO_4$ plots was about 0.7 of a unit lower than the $NaNO_3$ plots. The various sources of phosphorus used had no appreciable effect on pH.

TABLE 2.—*An inventory of the phosphate losses and accumulations in a 15-year period in the surface 16 inches of a Norfolk fine sandy loam.*

Plot No.	Source of nitrogen	Total P_2O_5 per acre in soil, lbs.			Total P_2O_5 per acre removed in seed cotton 1930–44, lbs.*	P_2O_5 per acre added from 1930–44, lbs.	Total P_2O_5 per acre lost or gained by subsoil 1930–44, lbs.†	Total P_2O_5 per acre unaccounted for in surface and subsoil and not removed in seed cotton, lbs.	Percentage of P_2O added from 1930–44 which is unaccounted for	Percentage of P_2O_5 added from 1930–44 which was removed by crop
		1929 0–8 in.	1944 0–8 in.	1944 8–16 in.						
					Tier 27, Limed					
1, 5, 9, 13, 17	$NaNO_3$	1,434	1,099	845	110	0	—	230	—	—
2	$NaNO_3$	1,467	1,771	1,026	112	900	183	301	33	12
3	$NaNO_3$	1,355	1,723	1,107	112	900	264	156	17	12
4	$NaNO_3$	1,411	1,715	930	109	900	86	401	45	12
6	$NaNO_3$	1,323	1,747	1,018	116	900	168	162	18	13
7	$NaNO_3$	1,571	1,764	1,194	127	900	344	236	26	14
8	$NaNO_3$	1,489	1,555	1,121	103	900	271	460	51	11
Average.....							219		32	
10	$(NH_4)_2SO_4$	1,667	1,643	853	130	900	25	769	85	14
11	$(NH_4)_2SO_4$	1,562	1,507	824	138	900	–8	825	92	15
12	$(NH_4)_2SO_4$	1,498	1,650	921	135	900	88	525	58	15
14	$(NH_4)_2SO_4$	1,435	1,547	850	138	900	17	633	70	15
15	$(NH_4)_2SO_4$	1,499	1,571	873	138	900	40	650	72	15
16	$(NH_4)_2SO_4$	1,506	1,523	930	131	900	96	656	73	15
Average.....							43		75	

Tier 28, Unlimed

1, 5, 9, 13, 17	$NaNO_3$	1,324	928	767	105	0	—	291	—	—
2	$NaNO_3$	1,289	1,290	768	109	900	42	748	83	12
3	$NaNO_3$	1,194	1,313	785	116	900	59	606	67	13
4	$NaNO_3$	1,292	1,344	802	120	900	76	652	72	13
6	$NaNO_3$	1,321	1,530	773	122	900	−20	589	65	14
7	$NaNO_3$	1,370	1,627	761	138	900	−36	469	52	15
8	$NaNO_3$	1,482	1,513	721	109	900	−27	787	87	12
Average.....							16		71	
10	$(NH_4)_2SO_4$	1,345	1,674	793	114	900	12	445	49	13
11	$(NH_4)_2SO_4$	1,362	1,490	760	114	900	−22	680	76	13
12	$(NH_4)_2SO_4$	1,467	1,442	735	122	900	−47	850	94	14
14	$(NH_4)_2SO_4$	1,338	1,627	753	122	900	−25	514	57	14
15	$(NH_4)_2SO_4$	1,250	1,434	721	117	900	−57	656	73	13
16	$(NH_4)_2SO_4$	1,274	1,506	730	95	900	−48	525	58	11
Average.....							−31		68	

*These values obtained by using 0.71 as the P_2O_5 content of seed cotton (4).
†Calculated by subtracting the average total P_2O_5 in the subsoil of the two closest check plots from the total P_2O_5 in the subsoil of a phosphated plot.

TABLE 3.—*Influence of soil treatment on soil reaction and dilute acid-soluble P_2O_5.*

Plot No.	Fertilizer treatments*	Tier 27, limed					Tier 28, unlimed				
		Truog-soluble P_2O_5 in p.p.m. 0–8 in.		pH			Truog-soluble P_2O_5 in p.p.m. 0–8 in.		pH		
		1929	1944	1929 0–8 in.	1944 0–8 in.	1944 8–16 in.	1929	1944	1929 0–8 in.	1944 0–8 in.	1944 0–16 in.
1	Check	51	50	6.0	6.3	5.9	45	26	6.0	6.0	5.7
2	Monosodium phosphate	52	96	6.1	6.2	5.9	41	64	6.0	6.0	5.9
3	Monocalcium phosphate	43	106	6.1	6.3	6.1	43	65	6.0	6.0	5.7
4	Dicalcium phosphate	53	120	6.0	6.3	6.0	52	85	6.0	6.1	5.8
5	Check	51	49	6.1	6.3	6.0	46	30	6.0	6.0	5.7
6	Tricalcium phosphate	45	226	5.9	6.3	5.9	46	153	6.0	5.9	5.7
7	Superphosphate	58	120	6.1	6.2	5.8	50	91	5.9	5.9	5.4
8	Monoammonium phosphate	54	86	6.0	6.0	5.4	49	56	5.9	5.7	5.5
9	Check	39	46	5.8	6.3	5.8	50	27	6.0	6.0	5.7
10	Monosodium phosphate	58	68	5.9	5.6	5.2	44	70	5.9	5.0	5.1
11	Monocalcium phosphate	59	76	6.1	5.6	5.2	46	60	6.0	5.1	5.1
12	Dicalcium phosphate	48	92	6.0	5.7	6.1	50	66	6.0	5.3	5.2
13	Check	52	43	6.1	6.3	5.3	53	28	6.0	6.0	5.9
14	Tricalcium phosphate	53	160	6.1	5.8	5.1	49	115	6.0	5.4	5.1
15	Superphosphate	59	88	6.1	5.6	5.1	41	68	5.9	5.1	4.9
16	Monoammonium phosphate	55	63	6.1	5.6	5.1	50	60	5.8	5.0	4.9
17	Check	47	39	6.0	6.3	5.8	52	30	6.0	5.9	5.7

*Check plots and plots 2, 3, 4, 6, 7, and 8 received $NaNO_3$ as source of nitrogen and all other plots received $(NH_4)_2SO_4$.

Dilute acid-soluble phosphorus was much higher in the limed plots than in the unlimed plots in case of both the check plots and phosphated plots. Plots receiving the more insoluble phosphate, such as tricalcium phosphate, contained the most acid-soluble phosphorus. In general, the lower the pH of the soil, the less acid-soluble phosphorus it contained.

Samples from certain plots were leached with neutral 0.5N NH_4F solution and phosphorus was determined in the extract. These values are reported in Table 4 along with the values for dilute acid-soluble phosphorus. It is pointed out that the tricalcium phosphate-treated soil contained almost twice as much dilute acid-soluble phosphorus as the superphosphate-treated soil. However, the NH_4F solution extracted more phosphorus from the superphosphate-treated soil. Also, the limed plots contained more dilute acid-soluble phosphorus

TABLE 4.—*The influence of treatment on the quantity of phosphorus extractable by different methods.*

Plot No.	Fertilizer		Tier 27, limed		Tier 28, unlimed	
	Source of phosphorus	Source of nitrogen	Truog-soluble P_2O_5, p.p.m.	NH_4F-soluble P_2O_5, p.p.m.	Truog-soluble P_2O_5, p.p.m.	NH_4F-soluble P_2O_5, p.p.m.
1, 5, 9, 13, 17	0	$NaNO_3$	47	163	28	135
6	Tricalcium phosphate	$NaNO_3$	225	205	153	208
7	Superphosphate	$NaNO_3$	120	312	91	299
14	Tricalcium phosphate	$(NH_4)_2SO_4$	160	225	115	283
15	Superphosphate	$(NH_4)_2SO_4$	88	322	68	332

than the corresponding unlimed plots, but the reverse was true for NH_4F-soluble phosphorus. Since neutral 0.5 N NH_4Cl solution did not extract any appreciable quantity of phosphorus from these samples (unreported data), it was assumed that most of the phosphorus extracted by NH_4F was anion exchangeable phosphorus.

SUMMARY

A study was made of the effect of soil reaction on the response of cotton to several sources of phosphorus on a Norfolk fine sandy loam. The sources of phosphorus tested were superphosphate, monosodium, monocalcium, dicalcium, tricalcium, and monoammonium phosphates. Soil reaction changes were brought about by the addition of lime and the continued use of two sources of nitrogen, $NaNO_3$ and $(NH_4)_2SO_4$. The influence of these treatments on the status of phosphorus in the soil was studied after cotton had been grown continuously for 16 years.

The results may be summarized as follows:

1. On the plots receiving $NaNO_3$, superphosphate gave the greatest increase in yield of seed cotton of any of the phosphates studied.

However, on plots receiving $(NH_4)_2SO_4$ this was not true. This would indicate a sulfur deficiency on the $NaNO_3$ plots. The greatest increase in yield of seed cotton from superphosphate was obtained on the unlimed, $NaNO_3$ plots and the least increase was obtained on the unlimed, $(NH_4)_2SO_4$ plots.

2. With the exception of the limed plots receiving $(NH_4)_2SO_4$, the efficiency of monocalcium, dicalcium, and tricalcium phosphates increased in the order named indicating a response to calcium.

3. The check plot yields show a response to lime. For the last 4-year period of the experiment, the check plots of the limed tier produced an average of 115 pounds more seed cotton than the check plots of the unlimed tier.

4. Monosodium and monoammonium phosphates were less efficient than the other phosphates. They were relatively less efficient for the last 4-year period than for earlier periods of the experiment. The largest increase in yield of seed cotton from these two phosphates was obtained on limed plots receiving $(NH_4)_2SO_4$.

5. Total phosphorus unaccounted for by chemical analysis of the surface 16 inches of soil and crop removal was considered lost by erosion. The unlimed tier lost an average of 70% of the added phosphorus by erosion and there was no difference between the plots receiving $NaNO_3$ and those receiving $(NH_4)_2SO_4$. On the limed tier, the $NaNO_3$ plots lost an average of 32% of the added phosphorus, while the $(NH_4)_2SO_4$ plots lost an average of 75%.

6. There was an appreciable movement of phosphorus into the subsoil on the $NaNO_3$ plots that had been limed.

7. Dilute acid-soluble phosphorus was highest in the limed plots which had received $NaNO_3$ and lowest in the unlimed $(NH_4)_2SO_4$ plots. Plots that had received tricalcium phosphate contained more dilute acid-soluble phosphorus than plots receiving superphosphate.

8. Neutral 0.5N NH_4F solution extracted more phosphorus from a superphosphate-treated soil than from a tricalcium phosphate-treated soil. The reverse was the case for dilute acid-soluble phosphorus. This would indicate that much of the tricalcium phosphate stayed in the soil as calcium phosphate.

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Pasture Renovation: I. Seedbed Preparation, Seedling Establishment, and Subsequent Yields[1]

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THE IMPROVEMENT or renovation of unproductive pastures has held the interest and attention of agronomists and farmers for many years. Topdressing grazing lands with fertilizers and manure has markedly increased production, but with such treatment improvement is often slow and the resulting pasture still retains the serious limitation of most permanent pastures, that of low midsummer yields. More recently, the objective in some pasture investigations has shifted to the establishment and maintenance of species of grasses and legumes which are better adapted for production during midsummer.

In the summer of 1942 five of the state experiment stations of the Northeast region,[3] in cooperation with the U. S. Regional Pasture Research Laboratory, initiated investigations in the renovation of unproductive pastures. The primary objective of this work was to increase the production of pastures, particularly during midsummer, by the replacement of weeds and other unproductive species with grasses and legumes which continue to grow during this hotter, drier period. In the attainment of this major objective experiments were initiated on three principal phases, namely, (a) seedbed preparation, seedling establishment, and subsequent yields; (b) comparative evaluation of different grasses and legumes under the various climatic conditions and soil types found at several state experiment stations; and (c) management practices for maintenance of the seeded grass and legume species. This paper presents results of investigations conducted at State College, Pa., on the first of these phases of the problem.

REVIEW OF LITERATURE

A brief review of some work in pasture renovation and of objectives and procedures is presented as a background for these experiments and for others still in progress at State College. For the most rapid improvement of pastures in the northeastern states, in 1910 Cotton (4)[4] recommended plowing the old sod, growing a cultivated crop for two or three years, and then reseeding with

[1]Cooperative investigations of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, State College, Pa., and the Departments of Agricultural Engineering, Agronomy, and Animal Husbandry of the Pennsylvania State College. Contribution No. 78, of the U. S. Regional Pasture Research Laboratory, State College, Pa. Part of this paper was presented at the annual meeting of the Society in Columbus, Ohio, March 1, 1946. Received for publication July 24, 1946.

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[3]Connecticut (Storrs), Massachusetts, Pennsylvania, Rhode Island, and Vermont.

[4]Numbers in parenthesis refer to "Literature Cited", p. 24.

timothy, redtop, Kentucky bluegrass, and white clover. If the land was too rough to plow, use of a disk or spring-tooth or peg harrow to work up the old sod and provide soil contact for the applied seed was recommended. It was generally recognized that the soils were acid and low in fertility, but the fertilizer recommendations were limited primarily to applying manure and spreading the droppings. Lime was recommended for poorly drained soils and commercial fertilizers containing phosphorus and potash were recommended for areas where a manure spreader could not be used.

Several years later, in West Virginia, Cook (3) reported considerable improvement of pastures from harrowing seed of red clover, timothy, and redtop into old sods in combination with lime, phosphate, and potash. This, however, appeared to be a response to increased fertility as shown by the heavier stands of white and hop clovers, rather than to the seeded species. Odland, *et al.* (9) applied lime, superphosphate, and manure to unproductive pastures with and without reseeding and with and without disking. Harrowing and seeding without lime and fertilizer were not effective. Even where lime and fertilizer were applied little additional increase in yield was obtained by harrowing and seeding. Increasing fertility of the old sods was reported to be the most effective procedure for improvement.

In Wisconsin, Graber (5, 6) increased the production of old Kentucky bluegrass pastures by the introduction of sweetclover. He found that it was necessary to remove the old growth of bluegrass either by burning or disking to permit soil contact with the seeded species and prevent severe competition during the seedling stage of the sweetclover. Grazing during the seeding year was carefully regulated to allow vigorous growth of the legume. Lime was used on acid soils. Increased amounts of feed were obtained due not only to the sweetclover but also to the increased yields of the Kentucky bluegrass. This probably was, in a large part, a result of the nitrogen supplied by the legume. A few years later, when white grub injury to bluegrass sods became widespread and serious in Wisconsin, Graber (7) found renovation particularly effective in reducing white grub injury as well as increasing pasture yields. The renovation practices included the application of lime and fertilizer, weakening and disking of the old sod, and the seeding of deep-rooted legumes, such as sweetclover, alfalfa, and red clover. These legumes repelled the egg-laying June beetles and increased the growth of the surviving Kentucky bluegrass.

More recently, Ahlgren, *et al.* (1), in a series of pasture renovation trials under regulated grazing on slopes varying from 15 to 35%, found that in the year after seeding the production of the renovated fields was over five times that of the untreated areas, but that the second year after seeding the yield of the renovated area had decreased to just over two times that of the unrenovated areas. In the first year after seeding the percentages of Kentucky bluegrass and redtop in the sod were low and sweetclover and red clover were high whereas in the second year after seeding the percentages of Kentucky bluegrass and redtop increased considerably, the red clover remained about constant, and the sweetclover was practically absent. It is evident that the grass on the renovated area was not killed by spring cultivation but probably was stimulated and increased in vigor and growth by the added mineral fertilizers, the nutrients liberated by the decomposing organic matter from the old sod, and the nitrogen furnished subsequently by the seeded legumes.

Borst and Yoder (2) obtained excellent stands of alfalfa on unproductive hillsides in Ohio by a system of adequate liming, fertilization, disking, and seeding. The original vegetation on these areas consisted primarily of poverty grass and broomsedge. Since these species cannot compete with the more vigorous forage species, it is only necessary that the alfalfa become well established and any native species which might remain would be crowded out. Thus, fertilization and disking in the spring followed by seeding was effective in obtaining stands of productive alfalfa.

Smith, *et al.* (10), on a number of farms in West Virginia, compared plowing and shallow tillage as methods of preparing the seedbed in pasture renovation. The seedbeds were prepared in the spring and lime and mineral fertilizers were incorporated into the soil. Seed was broadcast and was covered by a very light disking or harrowing. In the majority of cases, larger yields and better establishment of the seeded legumes were obtained on seedbeds prepared by shallow tillage.

Hughes and Peterson (8) in Iowa compared several methods of seedbed

preparation. Late fall plowing on the contour followed by disking and seeding in early spring was most effective in killing the old bluegrass sod. Good stands of the seeded legumes were obtained following this practice. On areas with a subsurface tiller, with a disk, and by spring plowing, Kentucky bluegrass readily volunteered and the stand of the seeded species was poorer.

MATERIALS AND METHODS

The site selected for these trials was on a gentle (5%) southeast slope on Dunmore silt loam which had not been tilled during the past 40 years. A combination of beef cattle and sheep had grazed the area each year for a considerable number of years. The condition of the pasture suggested that cropping had been discontinued because of moderately severe sheet erosion combined with depleted soil fertility. Predominant vegetation included redtop, *Agrostis alba* L., Kentucky bluegrass, *Poa pratensis* L., poverty grass, *Danthonia spicata* (L.) Beauv., Canada bluegrass, *P. compressa* L., hawkweed, *Hieracium sp.*, cinquefoil, *Potentilla* sp., and moss, *Polytrichum*, with occasional plants of white clover, *Trifolium repens* L.

PROCEDURE IN EXPERIMENT I

In the late summer of 1942, plots 15 feet by 72 feet were laid out in two replications to investigate the adaptability of several farm implements in seedbed preparation. The time and power required to work up the sod were determined, using several implements in different combinations. These methods of seedbed preparation included (a) shallow plowing with a mold board plow, (b) thorough disking with an orchard cover crop disk (7½ feet wide), (c) working with small field cultivator (4⅔ feet wide), and (d) working with an ordinary disk harrow followed by the field cultivator. To eliminate fertility as a factor in these trials, adequate lime (2 tons per acre) and mineral fertilizer (200 pounds P_2O_5 and 150 pounds K_2O) were worked into the soil at the time the seedbeds were prepared. Several weeks after the plots were first worked the entire area was disked once with an ordinary disk harrow to loosen those sods which had rooted down. All plots went through the winter without a cover crop or additional mulch. In March 1943, the surface had dried sufficiently to permit disking the entire area twice and rolling with a corrugated roller once before seeding and once after seeding. All plots were seeded on March 31, 1943, with a uniform mixture which included red clover, *Trifolium pratense* L., at 3 pounds per acre; alfalfa, *Medicago sativa* L., at 4 pounds per acre; Ladino clover, *T. repens* L. at 1 pound per acre; orchard grass, *Dactylis glomerata* L., at 3 pounds per acre; bromegrass, *Bromus inermis* Leyss, at 4 pounds per acre; and timothy, *Phleum pratense* L., at 2 pounds per acre.

For yield measurements, three strips, 40 inches by 16 feet, were harvested from the center of each plot with a sickle bar power mower. Green weights were recorded and samples were taken for the determination of moisture and for botanical analysis by manual separation of grass, weeds, and of the several species of legumes. The several grass species were not separated but recorded as "grass". The time of harvesting was determined by the stage of growth of the several species present with the primary objective of maintaining the legumes, particularly Ladino clover, in the sward.

To evaluate the responses from the renovation treatments, yields were obtained from plots on the untreated sod and also from plots that were top-dressed with lime and fertilizer at the same rate that was used on the renovated plots. Herbage yields on the unrenovated plots were determined by clipping with a lawn mower. These plots were adjacent to but not randomized with the renovated plots.

PROCEDURE IN EXPERIMENT II

In August 1943, an additional series of plots, 20 feet by 75 feet, was laid out in two replications to investigate further the use of various implements in the preparation of the seedbed. In these trials seedbeds were prepared by (a) shallow plowing with a mold board plow, (b) shallow plowing with a disk plow, (c) working the sod twice with a heavy cover crop disk (7½ feet wide), (d) working the sod with a large field cultivator (10 feet wide), (e) working the sod with a sod cutter or sweep which cut the sod below the surface but did not turn it up, and (f) weakening

the vegetation by close fall and spring clipping without disturbing the sod. The plots that had been worked with the various implements were cross disked once as a unit since it was evident that with such implements as the sod cutter the plants would root again after the first rain and the vegetation would not be killed. The entire worked area was disked again in the latter part of September 1943 to turn up and loosen sods which had rooted down.

On March 31, 1944, the following three mixtures of grass-legume seeds were sown in triplicate on subplots of each of the plots prepared by the several implements: (a) Red clover at 4 pounds per acre, alfalfa at 6 pounds per acre, Ladino clover at 1 pound per acre, and orchard grass at 5 pounds per acre; (b) the same legumes with smooth bromegrass at 6 pounds per acre; and (c) birdsfoot trefoil, *Lotus corniculatus* L., at 4 pounds per acre and orchard grass at 5 pounds per acre. The seed was broadcast on frozen ground without harrowing or cultipacking. The rates of lime and fertilizer application, frequency of clipping, and methods of obtaining yields and botanical composition were similar to those in experiment I.

EFFECTIVENESS OF VARIOUS FARM IMPLEMENTS IN SEEDBED PREPARATION

PREPARATION OF THE SEEDBED IN EXPERIMENT I

Each plot, 15 feet by 72 feet, was worked up as a unit; the speed of the tractor, the horsepower required, and the number of times it seemed necessary to go over a plot were recorded. From these data it was possible to estimate the number of acres per day which could be prepared and the amount of work which would be required (Table 1). It is evident from these data that on this land which had few stones the plow was the most economical implement to use. This may in considerable part be due to the fact that the disks used were not heavy enough and could not be weighted down sufficiently to cut adequately into the sod. Further, with small plots it was not possible to cross disk so that the disking was all in one direction. Thus, the disks in a second or third disking tended to follow the grooves cut by the first disking. The type of field cultivator used in this trial was not well adapted for the purpose. The bluegrass sods tended to roll up and clog the teeth. Cutting the sod first with a disk helped appreciably in preventing clogging.

TABLE 1.—*Estimated time and work required to prepare a seedbed with several farm implements, experiment I, 1942.*

Implements used	Estimated acres per day which could be worked	Estimated drawbar horsepower hours per acre
Mold board plow, 2 bottom, 14-inch, shallow (4 in.) plowing	6.3	12.5
Cover crop disk, 7½ feet wide with 22-inch disks, four times lengthwise over the plot	5.1	21.3
Field cultivator, 4⅔ feet wide, four times lengthwise over the plot	2.6	25.0
Ordinary disk harrow, 7½ feet wide with 16-inch disks, two times lengthwise over the plot; then field cultivator, two times lengthwise over the plot	4.2	20.3

The most complete kill of the existing vegetation was obtained by plowing; the sod was completely turned under and almost no grass

volunteered. However, during the fall and winter of 1942–43 there was considerable sheet erosion on the plowed areas, even though the slope was only about 5% and the plots (only 15 feet wide) were arranged across the slope. On adjacent plots which were prepared with a disk or field cultivator and where the remnants of the old sod remained in or on the surface, no erosion was evident.

PREPARATION OF THE SEEDBED IN EXPERIMENT II

In preparing the seedbeds for experiment II the first working of the sod was delayed until after a rain (.82 inch on August 27, 1943) had softened the soil. As in the previous experiment, the acres per day which could be worked by the various implements and the work necessary to operate them were calculated (Table 2). It will be noted that the estimated number of acres per day and the amount of work required are more nearly the same for the several implements than in experiment I. With the type of field cultivator used in 1943 the old sod was satisfactorily broken up without difficulty from clogging. While the sod cutter or sweep followed by a cross disking prepared a good seedbed, it has the disadvantage of not being adapted to use on stony land. Furthermore, extra care must be taken to disk thoroughly to turn up sod which was cut by the sod cutter or sweep but left in place; otherwise it may easily root down again.

TABLE 2.—*Estimated time and work required to prepare a seedbed with several farm implements, experiment II, 1943.*

Implements used	Estimated acres per day which could be worked	Estimated draw-bar horsepower hours per acre
Mold board plow, 2 bottom, 14-inch, shallow (4 in.) plowing	6.3	12.6
Cover crop disk, 5 feet wide with 22-inch disks, two times lengthwise and once crosswise over the plot*	4.5	17.6
Disk plow, three 26-inch disks, shallow (4 in.) plowing; then cover crop disk as above, once lengthwise over the plot	4.5	17.7
Sod cutter, 5 feet wide with 24-inch sweeps, set to cut 2½ to 3 inches deep; then cover crop disk as above, once crosswise over the plot	6.7	13.4
Field cultivator, 10 feet wide, twice over the plots; then cover crop disk as above, once crosswise over the plot	6.5	14.5

*A heavily weighted cutaway disk with disks 24 inches in diameter was used in preparing other areas in August 1944. This implement appeared to penetrate deeper than a solid disk, particularly the first time over the field. No records were taken of the power and time required, but observations indicated that the cutaway disk may prepare a seedbed with fewer drawbar horsepower hours than a solid disk, or it may prepare a better seedbed with the same amount of work.

Shallow plowing with the disk plow turned the sod up on edge so that it was very susceptible to drying and killing. However, the land was left so rough that disking and harrowing the surface later in the season would be advisable if haymaking machinery were to be used on the field. On the plots plowed with a mold board plow there was

some slight erosion during the fall and winter, but it was not as great as that on the plowed plots established the previous year. Part of the difference may have been due to the type of fall and winter precipitation, but observations indicated that the plowing in August 1943 had not turned the sods over as completely as had been the case the previous year. Therefore, more of the old sod remained at or near the surface, thus reducing erosion.

SUPPLEMENTARY TRIALS

From the two experiments started in 1942 and 1943 it became evident that a primary requisite in seedbed preparation was killing of the old sod and leaving it on or near the surface. The following year a heavy cutaway disk (bush and bog harrow) became available for use in preparing the seedbed for renovation of several other pasture areas.[5] This implement (Fig. 1) has large disks and is strongly

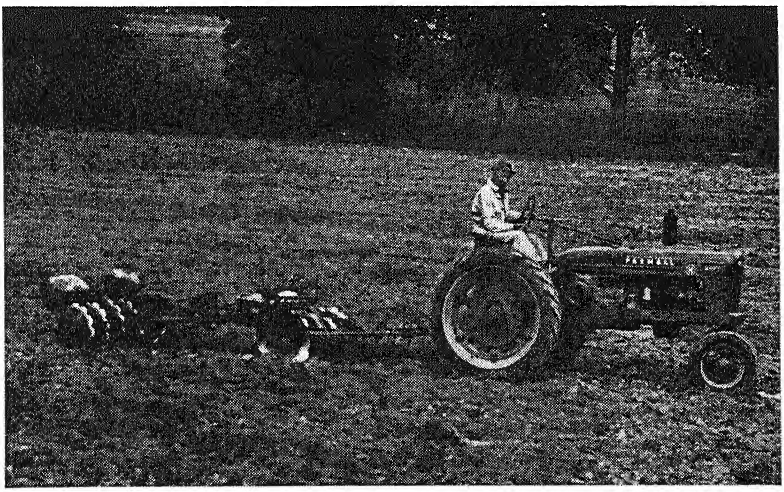

FIG. 1.—A heavy 24-inch cutaway disk (bush and bog harrow) used in renovating an unproductive pasture.

built so that it can be used on rough or stony land and can be heavily weighted. It was found that in working the land, after a rain had softened the surface few inches, it was advisable to use only the front section heavily weighted and lapping half the first time over the field. When both sections were weighted sufficiently to cut the sod well, the tractor wheels slipped. After the field was disked once, it was cross disked using both sections of the disk, but less heavily weighted. This turned up most of the sod so it was killed by the hot, dry weather normally common in August. Lime was applied before the

[5]The authors wish to thank Doctor S. I. Bechdel, Professor of Dairy Production at the Pennsylvania Agricultural Experiment Station, for the use of the cutaway disk and for providing other facilities used in preparing the seedbeds.

first disking. After several weeks mineral fertilizers (phosphate and potash) were applied and the entire field was disked again, using both sections of the disk. This turned up sods which had rooted since the first disking and incorporated the fertilizer in the surface 3 or 4 inches of soil.

Seedings of various combinations of grasses and legumes, including alfalfa, sweetclover, *Melilotus officinalis* (L.) Lam., Ladino clover, birdsfoot trefoil, orchard grass, tall oat grass, *Arrhenatherum elatius* (L.) Prese., and bromegrass, were made on frozen ground in March 1944 without additional working of the seedbed. Since this was a relatively small area in a large pasture grazed by dairy cattle, it was not feasible to fence it to prevent grazing while the seedlings were becoming established. To prevent overgrazing of the young seedlings, about 1 ton per acre of manure was applied to two strips of the seeded area shortly before the cattle were turned in to graze. Observations several weeks later revealed that where the manure had been applied the seedlings had been grazed uniformly to a height of 6 to 8 inches above ground level whereas on the areas not manured, the seedlings were eaten almost to ground level. Since this area was pastured no yields were taken from any of the plots.

FORAGE PRODUCTION FROM THE VARIOUS METHODS OF SEEDBED PREPARATION

SEEDLING ESTABLISHMENT AND YIELDS IN EXPERIMENT I

Observations on emergence and growth of the mixture of red clover, alfalfa, Ladino clover, orchard grass, bromegrass, and timothy seeded on March 31 were made during the spring and summer to determine whether there were differential effects due to the several methods of seedbed preparation. Seedling emergence on the plowed plots, particularly of the smaller seeded species like Ladino clover was somewhat poorer than on the other plots on which the old sod remained and in the surface layer of soil. Puddling of the surface soil on the plowed plots and a subsequent crusting over appeared to make seedling emergence more difficult. In July and August of the year of seeding (1943) rainfall was limiting and growth on all plots was inhibited. On the plowed areas this was particularly serious (Fig. 2), resulting in the death of most of the Ladino clover and timothy seedlings and causing severe wilting of the alfalfa, orchard grass, and bromegrass. On adjacent plots prepared by the disk or field cultivator, only slight wilting of the plants was evident. Observations made during a heavy shower indicated that runoff from the disked plots was negligible, whereas on the plowed plots moisture infiltration was inhibited by the puddled soil surface and runoff was excessive.

The following year (1944) top growth of the seeded species provided protection for the soil surface so that moisture infiltration was similar on all plots and the yields of dry matter (Fig. 2) from various methods of seedbed preparation were almost identical (Fig. 3). In 1945 the plowed areas yielded slightly more than those prepared by the other implements, probably due to the larger amount of alfalfa on these plots as revealed by botanical analysis of the herbage. The average

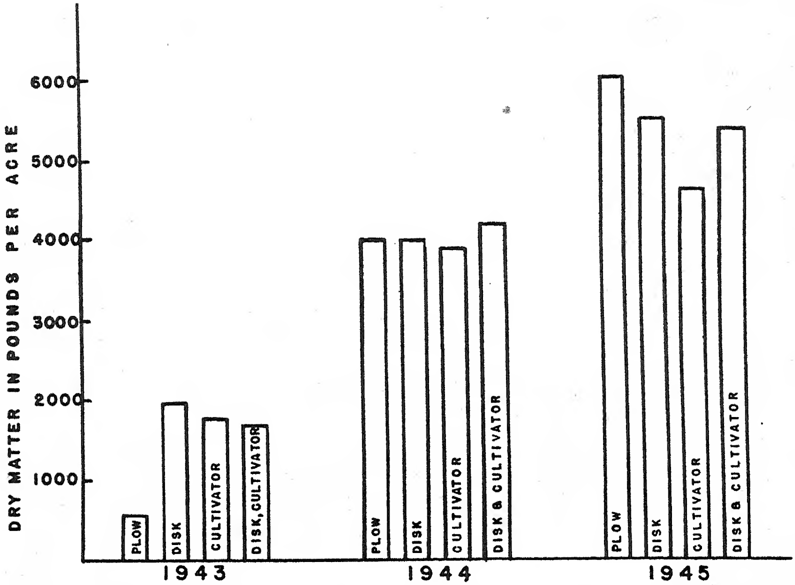

FIG. 2.—Yields of dry herbage produced on seedbeds prepared by various farm implements in early September 1942 and seeded with the grass-legume mixture on frozen ground on March 31, 1943.

FIG. 3.—Summer growth of the grass-legume association on the area prepared by disking in August 1942 and followed by seeding in March 1943. Photographed July 16, 1944.

yield of plots prepared by the field cultivator was slightly below the yields of the other plots, but it is believed that this was due to the low yield of one replication and does not truly reflect the effectiveness of the implement.

It is evident from the above data that, while the plowed plots yielded the least during the year of establishment, primarily due to a serious deficiency in soil moisture, the yields in subsequent years were similar. It is further evident that the organic matter from the old sod should remain on or near the surface to prevent erosion, to increase moisture infiltration, and to provide conditions suitable for the emergence of the legumes and grasses.

Increases in herbage yield by top-dressing with lime and fertilizer but without tillage or reseeding were small during the first two years (Fig. 4). This sod had so few plants of white clover and Kentucky bluegrass to serve as nuclei that the process of changing the botanical composition of the sward was slow, and until clover became estab-

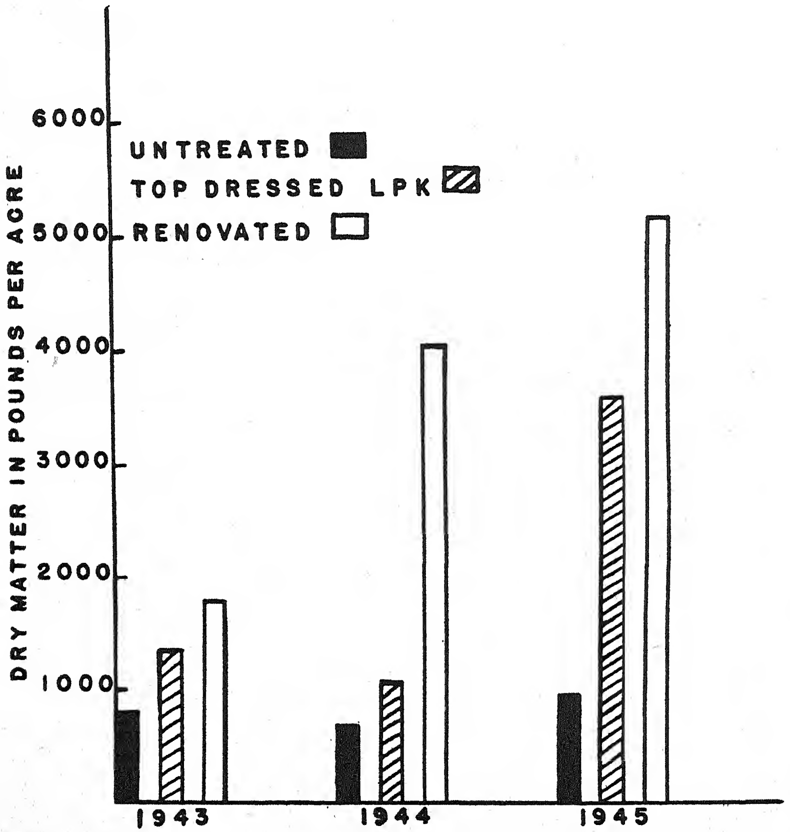

FIG. 4.—Yields of dry herbage produced on the untreated pasture, on plots top-dressed with lime and fertilizer, and on plots that were surface cultivated, fertilized, and seeded. Experiment I.

lished to provide nitrogen for the growth of the grass little increase in vigor could be expected.

SEEDLING ESTABLISHMENT AND YIELDS IN EXPERIMENT II

Herbage yields (Fig. 5) were obtained during 1944 and 1945 from the plots prepared by the several implements and from those on which the existing herbage had been severely weakened. These latter plots were clipped closely in the fall of 1943 and in the spring of 1944 until the seeded species reached a height of about 1 inch. The yields from the plowed plots, in contrast to those obtained in experiment I,

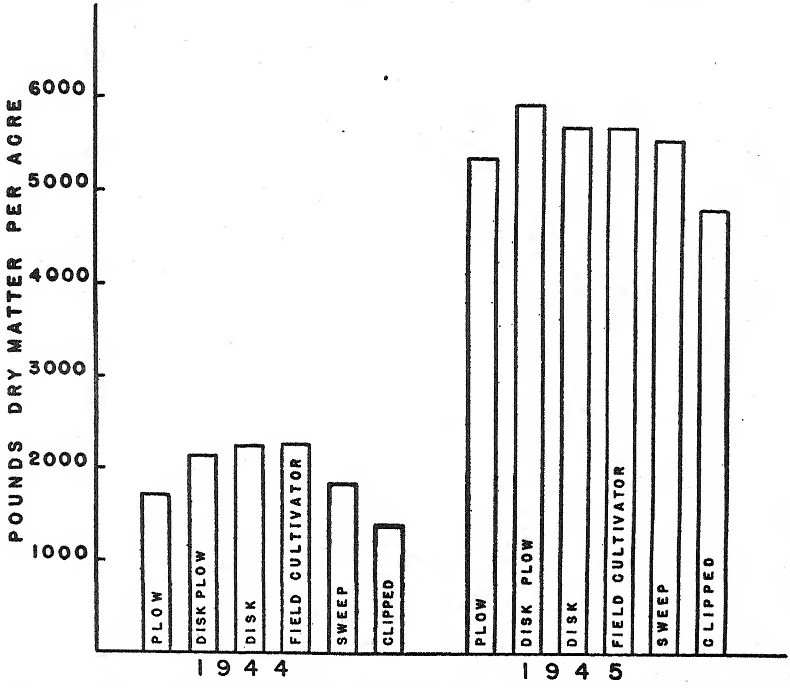

FIG. 5.—Yields of dry herbage produced on seedbeds prepared with various farm implements in late August 1943. These yields are the averages of two mixtures: (a) alfalfa, red clover, Ladino clover, and orchard grass; and (b) alfalfa, red clover, Ladino clover, and bromegrass seeded on frozen ground March 31, 1944. Experiment II.

approached the yields of plots prepared by surface cultivation. This may be attributed to a so-called poorer job of plowing which left more organic matter on the surface. The yields of the plots where the sweep was used were slightly below those prepared by the disk plow, the cover crop disk, and the field cultivator. This reduction was probably due to a less complete kill of the original sod which competed with the seeded species during establishment. In these trials, as in those of experiment I, the yields of the plots prepared by the various implements were practically identical the second year after seeding.

On the tilled areas an excellent stand of all seeded species was obtained. In contrast, it was observed that only red clover and Ladino clover became established to any extent on the areas where the existing vegetation was weakened by clipping. A small number of seedlings of alfalfa, birdsfoot trefoil, and orchard grass plants were evident and only a very few scattered plants of bromegrass could be found. The slowness of establishment and of growth of the seeded species during the first year is evidenced by the low yields in 1944 (Fig. 5). A botanical analysis of the herbage yields in 1945 on the plots that were not tilled indicated that red clover contributed about one-half of the yield, Ladino clover about one-fourth, and the remainder was largely Kentucky bluegrass with a small amount of alfalfa.

DISCUSSION

Successful renovation of unproductive pastures is dependent upon three major items, as follows:

1. It is essential to supply lime and fertilizer to meet the requirements of the species which are to be used. The actual amounts of these soil amendments will vary with the acidity and fertility level of the soil and the species of legumes and grasses which it is desired to establish and maintain.

2. A seedbed must be prepared in which the existing vegetation is killed or subdued sufficiently to prevent serious competition with the seeded species. The completeness of kill of the old sod which is necessary is determined by the species which compose it and by the ability of the seeded species to compete with them during the seedling stage.

3. After the establishment of the desired species, a system of grazing management and subsequent fertilization should be followed which will provide favorable growing conditions for these plants and thus maintain the pasture in a productive condition. The details of these management practices will vary, depending on the species used and the requirements of the farm program.

The implement best adapted for preparing a satisfactory seedbed will be determined to a considerable extent by topography of the land and stoniness of the soil. In much of the Northeast Region surface tillage implements such as the disk and field cultivator probably would be more effective than plowing. Surface tillage, in addition to being the only adaptable method of tilling rough and stony land, has the advantage over plowing of leaving the old sod for a mulch. Organic matter on or near the soil surface largely prevents puddling by beating rains, permits more rapid infiltration of moisture, and decreases runoff and erosion. In contrast, the surface layer of plowed land may puddle badly, resulting in increased runoff and erosion, and may make seedling emergence more difficult. This is shown by the low yields obtained during the year of seeding on the plowed plots in experiment I. The magnitude of this difference will depend to a considerable extent on the soil, weather conditions, and completeness of turning under the old sod.

A particularly useful implement is the heavy cutaway disk (bush and bog harrow) which may be heavily weighted and used on rough land to cut the old sod. The adaptability of this disk for use in renovating pastures is indicated further by unpublished results from several of the agricultural experiment stations in New England. Prince[6] and his associates have been using the bush and bog disk in renovating pastures in New Hampshire for the past 7 years. This disk has usually been used on land which was too rough and rocky to plow. In two comparisons made between the bush and bog disk and the mold board plow, the time required to prepare a satisfactory seedbed was somewhat less with the disk than with the plow. Yields of forage on disked land were entirely satisfactory. However, in the third year on the land prepared by fall disking, more Kentucky bluegrass and bentgrass volunteered than on land which had been plowed. Colby reported[7] that a grass sod which was closely grazed could be killed rather readily with a bog harrow and that it was particularly effective in destroying a "moss-cinquefoil" type of sod. Furthermore, he found this implement outstanding for use on erodable land where it is essential to minimize soil and water losses. Midgley reported[8] similar results and, in addition, stated that, while the cutaway harrow required considerable power, the cost of preparing a seedbed was usually less with disking than with plowing. Stuckey concluded[9] that the use of a bush and bog harrow with sufficient power to pull it is the most successful way of working up a seedbed.

Results obtained with a field cultivator were also very satisfactory. It would appear, however, that some types of field cultivators are better adapted than others for breaking up pasture sods. The implement used in experiment I clogged badly, whereas no difficulty was experienced with the implement used in experiment II. The type of shovel may be a factor in clogging. The shovels were 18 inches apart in both implements, but the design of the shovels differed considerably. Those on the cultivator used in experiment I were attached rather rigidly to the frame, whereas the shovels on the implement used in experiment II were of the heavy spring-tooth type. The sods broke through between the shovels of this latter type implement. The height of the frame above the ground was 15 inches in both cultivators.

Top-dressing with lime and mineral fertilizer greatly improves unproductive pastures. However, as in the present trials, the response is often slow, requiring 1 to 3 years, depending largely upon the botanical composition of the original sod. Furthermore, the resulting improved pasture usually will not contain the species of grasses and legumes which are most productive during midsummer when pasture herbage is usually limited.

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[6]Prince, Ford S. Personal communication, 1946.
[7]Colby, William G. Personal communication, 1946.
[8]Midgley, A. R. Personal communication, 1946.
[9]Stuckey, I. H. Personal communication, 1946.

SUMMARY

Renovation trials were started in 1942 and 1943 on an old unproductive pasture on Dunmore silt loam at State College, Pa., to determine the adaptability of various farm implements and the factors involved in preparing a seedbed for several of the deeper rooted and higher yielding grasses and legumes. The implements used included the mold board plow, disk plow, two types of field cultivators, ordinary disk harrow, cover crop disk, cutaway disk, and sod cutter (sweep). Additional plots of the existing sod were weakened by close clipping before seeding. Lime and heavy rates of phosphate and potash fertilizer were applied so that soil fertility would not be a limiting factor. The following species were seeded in late winter on frozen ground in various combinations: Alfalfa, red clover, Ladino clover, birdsfoot trefoil, orchard grass, bromegrass, and timothy.

The results of these trials indicated that the farm implements used differed somewhat in their adaptability in preparing a seedbed for pasture grasses and legumes. On land that is plowable the use of a mold board plow was slightly more rapid and as economical as any of the other implements and was more effective for killing the old sod. The organic matter of the old sod was turned under, however, with little or no surface mulch to prevent puddling, runoff, and erosion. The other implements used were all approximately equal in power requirements and in the type of seedbed prepared. The heavy disk, and particularly the cutaway type, appeared to be adaptable to the widest range of land and sod conditions. With the use of any surface tillage implement it was essential to rework the land at least once and sometimes twice after the initial tillage to turn up those sods which had rooted down so they would be killed by desiccation. The sod cutter or sweep was least adaptable since it cannot be easily used on stony land; in addition, it cut the sod underground and left it in place where it could easily root again.

On areas which were not tilled but were severely clipped to weaken the existing sod and limed, fertilized, and seeded, a fair stand of Ladino clover and red clover became established. Only scattered plants of alfalfa, birdsfoot trefoil, and the seeded grasses were found.

The response from top-dressing on this unproductive sod with lime, phosphate, and potash was delayed until the third year by which time a sufficient amount of white clover and Kentucky bluegrass had become established to increase herbage yields.

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Soil Sampling From Fields of Uniform and Nonuniform Appearance and Soil Types[1]

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IT IS often true that in characterizing the chemical or physical properties of an area the errors incurred in sampling soils in the field are greater than the analytical errors in the laboratory. The soils literature abounds in methods of chemical analysis, but there has been relatively little research on the intensity and distribution of field borings required to give accurate samples for analysis. Where sampling methods have been proposed the distribution of the borings often has been impractical and suggestions with respect to the intensity of borings have involved assumptions that were not well founded on experimental evidence.

The literature dealing with soil sampling has been reviewed recently by Cline (2).[3] He also outlined the general principles of soil sampling and emphasized the necessity for more research upon which precise sampling standards could be based. Much of the literature has been concerned primarily with the soil survey (5, 12), although a few investigators have reported on variations in chemical properties from point to point within smaller areas (1, 3).

As Cline has pointed out, the selection of a single composite sample is justified if an unbiased estimate of the mean is the sole objective. If any property other than the mean is desired, however, a single composite sample would be inadequate. For certain objectives it may be just as important to know something of the variability within an area as to know the mean (9, 10, 11). Early investigations by Waynick (9, 10) and his coworkers and by Robinson and Lloyd (5) present some of the best discussions of the problems involved in obtaining a proper composite. Waynick presents data to show that the making of a composite sample is justified, but only after the variations in the area to be sampled are known. He found that under soil conditions such as he studied, composites of a limited number of soil samples, as 10 or 16, were subject to wide variations and could be used only when a low degree of accuracy was acceptable.

The need for the present investigation arose in connection with sampling soils for characterization of areas regarding certain chemical properties of the soils. These areas varied from plots a fraction of an acre to fields several acres in size. The accuracy desired of the samples varied from a description of the general fertility levels in some fields to accurate measurements in ppm or percentages in others. The purpose for which a sample is taken, therefore, may influence the intensity of borings in the field, the manner of compositing and subsampling the soil collected, and the laboratory techniques used.

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[3]Figures in parenthesis refer to "Literature Cited", p. 39.

The purpose of this report is to present techniques for isolating the major sources of error in a sampling procedure and for evaluating the effect of reducing the magnitude of some of the errors. The data are not sufficiently extensive to warrant any general recommendations regarding the intensity of field sampling, but they can contribute a little to the meager information on this subject.

METHODS

FIELD SAMPLING

Since the number of samples required or the number of borings necessary for a sample should depend, among other things, on the relative uniformity of the field, two areas were selected with the following characteristics:

I. *Uniform area.*—Norfolk fine sandy loam occurring on level area, and having a uniform appearance and soil type.

II. *Nonuniform area.*—Mixed Cecil and Appling fine sandy loam to clay loam occurring on rolling land. Erosion was pronounced and the area was not at all uniform in color, texture, or depth of topsoil, but typical of many areas in the Piedmont Plateau of central North Carolina.

Both had been cultivated for many years. The soils were of medium fertility level, had been moderately fertilized, but had received no heavy application of fertilizer in localized bands within the last two years. At the time that field I was sampled (July, 1943) it had on it a good growth of lespedeza. Field II had just been plowed and prepared for seeding small grain (September, 1943). The history of these fields for the three years previous to sampling is given in Table 1.

TABLE 1.—*Field history of areas used in sampling studies.**

Year	Crop	Fertilizer treatment per acre	Approximate yield per acre
		Field I—Norfolk Fine Sandy Loam	
1941	Cotton	400 lbs. 4–8–8	1 bale
1942	Wheat	Topdress 150 lbs. nitrate soda	25 bushels
1942	Lespedeza	None	1½ tons hay
1943	Wheat	Topdress 150 lbs. nitrate soda	15 bu. (cold damage)
1943	Lespedeza	None	——
		Field II—Mixed Cecil and Appling Fine Sandy Loam and Clay Loam	
1941	Corn	400 lbs. 3–12–6	30 bushels
1942	Oats	300 lbs. 2–12–6	
1943	Oats	Topdress 150 lbs. nitrate soda	40 bushels
1943	Fallow when sampled		

*Neither field had been limed within last 10 years.

In each field individual samples were taken at 20 "positions" equally spaced over an area approximately ¾ acre in size, as illustrated in Fig. 1. In addition, six samples were taken within a 6-inch radius of position No. 1 and are referred to below as "borings". Finally, a "bulk sample", which was a composite of 15 to 20 "borings", was taken from a location near position No. 1 in each field. A small spade with attached sides was used in taking the samples so that the same volume of soil could be taken from each position or boring. The soil was sampled to a depth of 6 inches, thus confining samples to the portion of the soil that had been cultivated and mixed in previous years.

PREPARATION AND CHEMICAL ANALYSES

All the samples were dried, broken up to pass a 1-mm sieve, and passed through a riffle sampler 20 times. Determinations were made for pH, readily soluble phos-

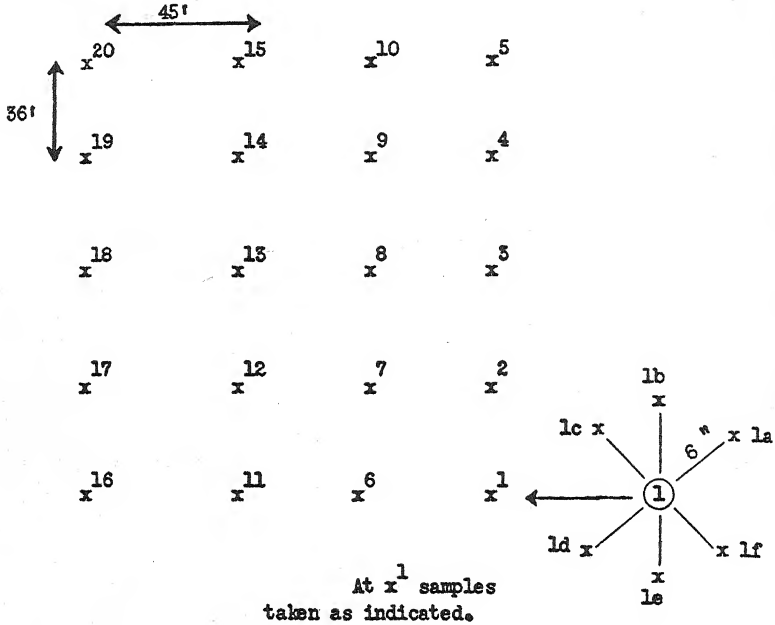

FIG. 1.—Location of boring positions in fields sampled.

phorus, exchangeable calcium and potassium, and easily oxidizable organic matter. In making these analyses, from each individual boring and position duplicate subsamples were drawn. From 5 to 10 subsamples of the "bulk sample" were analyzed for each constituent. In the case of phosphorus, where the procedure involved extraction, duplicate aliquots of the extract were taken on samples from the uniform area. This made possible a study of error due to technique of analysis, subsampling for analysis, and sampling in the field.

Briefly the methods of determination used were as follows:

pH—As outlined by Reed and Cummings (4).

Easily soluble phosphorus.—As proposed by Truog (7).

Exchangeable potassium and calcium.—Forty grams of soil were shaken for 30 minutes with 400 ml of 0.05 N HCl. After filtration, 75 ml aliquots were used for K and for Ca determinations. Iron and aluminum were removed by adding NH_4OH and filtering. Volk's (8) procedure was followed for removal of ammonia with NaOH and subsequent volumetric determination of potassium. Calcium was precipitated as the oxalate and determined volumetrically by permanganate titration.

Easily oxidizable organic matter.—A modification of the Walkeley—Black method was used. Into a 250-ml Erlenmyer flask was placed 1.25 grams of soil. To this was added 25 ml of 0.4 N sodium dichromate and then rapidly 25 ml of concentrated sulfuric acid. The flask was allowed to cool to room temperature and the contents diluted to 250 ml. Three drops of orthophenanthroline indicator (0.025 M) were added and the excess chromate titrated with 0.4 N ferrous ammonium sulfate. The end point was reached when the color changed from blue to reddish-brown. A blank titration was made of 25 ml of the sodium dichromate mixed with 25 ml of the concentrated sulfuric acid. The net ml of ferrous ammonium sulfate used, multiplied by 0.2, was taken as the percentage of organic matter.

RESULTS

STATISTICAL PROCEDURES

The statistical methods available for predicting the accuracy of means from a knowledge of the variation among individual samples are based on the assumption of random distribution of the samples. Since the 20 positions in each of the fields studied were uniformly spaced in a 5×4 grid pattern, it is of interest first to obtain some indications of the effect of the systematic pattern on the variation between positions. An analysis of the data was made for each constituent in each field, since if any marked gradients existed in the fields they should be picked up by the rows or columns of the grid. However, in no case were rows or columns significantly greater than the residual error. Therefore, in the absence of an estimate of position variation based on truly random distribution, it was assumed that the total variation between these 20 systematically distributed positions could be used without undue bias.

Variation associated with the determination of the chemical or physical properties of a soil may originate from several sources such as (a) position-to-position variation within the area, (b) variations in sub-sampling the soil drawn from the area, and (c) variations accompanying each step of the analytical procedure. It is necessary to have some concept of the magnitude of the variation from each of these sources in developing efficient sampling techniques.

As previously indicated, the samples representing the 20 positions were subsampled in duplicate in the laboratory, and, in the case of phosphorus analyses, duplicate aliquots were drawn from the extract of each subsample (Table 2). These data afforded the statistical analysis shown in Table 3, section A. An examination of the individual analyses in Table 2 revealed such a gross error between the two subsamples from position 11 that it was omitted from the analysis. This seems justified inasmuch as any alert technician would likely notice such errors during analysis. The soil from the six borings around the first position was also subsampled and duplicate aliquots taken from each subsample for phosphorus determinations. The analysis of these data is given in section B of Table 3. Likewise, 10 subsamples were drawn from the large composite of soil and this analysis is indicated in section C of Table 3.

Since the variation among subsamples and aliquots in the three analyses represent the same physical sources of error, these estimates were pooled to give the analysis in section D of Table 3. The same general procedure of obtaining a pooled analysis was followed in each of the other sets of data.

The algrebraic composition of the various mean squares is also given in Table 3 to indicate the usual procedure (6) for estimating the true or independent variances. Actual computions of true variances were made only on the pooled analyses. The variance for borings was determined from the six borings about only one position and can hardly be assumed to represent accurately the variation around the other positions. However, it is included in the analyses as an indication of the pattern of field variation. Since it is unlikely that a prac-

TABLE 2.—*Individual determinations of phosphorus from uniform and nonuniform areas.*

Position	Uniform area				Nonuniform area	
	Subsample 1		Subsample 2		Subsamples	
	1st aliquot	2nd aliquot	1st aliquot	2nd aliquot	1	2
1	30	30	28	28	17	20
2	25	25	26	27	15	13
3	38	38	39	39	9	11
4	24	23	26	26	28	31
5	26	25	27	28	20	22
6	29	28	29	29	17	17
7	26	27	30	29	30	32
8	24	25	26	25	14	14
9	25	25	24	24	24	24
10	30	28	30	29	26	26
11	17	19	33	38	12	13
12	27	26	29	28	7	9
13	25	25	24	28	24	27
14	36	36	34	32	57	55
15	29	29	28	27	10	11
16	31	30	29	32	14	13
17	27	27	28	24	7	9
18	33	32	37	35	31	29
19	26	27	33	34	14	14
20	35	36	35	33	17	18
			Borings—Position 1			
1A	32	33	27	28	23	22
1B	33	32	29	28	11	13
1C	33	34	27	28	15	16
1D	38	37	38	37	19	21
1E	28	29	30	31	19	21
1F	35	35	38	38	19	22
			Subsamples of "Bulk" Sample			
—	40	39	—	—	—	9
—	42	43	—	—	—	8
—	40	41	—	—	—	9
—	41	43	—	—	—	9
—	42	43	—	—	—	8
—	39	41	—	—	—	7
—	43	43	—	—	—	—
—	40	40	—	—	—	—
—	42	41	—	—	—	—
—	39	39	—	—	—	—

tical sampling system would require more than one boring at a position, the ultimate computations are unaffected by the poor estimate of boring variance.

On the basis of random sampling, the sources of variation shown in Table 3 can be combined to predict the efficiency of any sampling scheme by computing the variance of the mean on a per-determination basis as follows:

$V_{\bar{x}} = \frac{V_p}{p} + \frac{V_b}{b} + \frac{V_s}{s} + \frac{V_a}{a}$ where V_p, V_b, V_s, and V_a are estimates of the true variances obtained as in Table 4, and p, b, s, and a are the number of positions, borings, subsamples, and aliquots per sample, respectively. Thus, the variance of the mean phosphorus content of 20 positions with one boring at each position and one subsample and one aliquot determined for each position would be

$$V_{\bar{x}} = \frac{2.60}{20} + \frac{11.10}{20} + \frac{3.07}{20} + \frac{0.81}{20} = 0.88.$$

The variance of a *composite* of 20 positions with one boring at each position and a single determination on one subsample of the composite would be

$$V_{\bar{x}} = \frac{2.60}{20} + \frac{11.10}{20} + \frac{3.07}{1} + \frac{0.81}{1} = 4.57$$

The latter sampling scheme is perhaps the one most suited to soil sampling problems and will be considered again later.

TABLE 3.—*Analyses of variance of phosphorus determinations on soil from uniform and nonuniform areas.*

Source of variation	Degrees of freedom	Mean square	Composition of mean square*	Estimate of true variance
		Uniform Area		
		A. Positions		
Positions	18	61.78	$V_a+2V_s+4(V_b+V_p)$	——
Subsamples	19	5.79	V_a+2V_s	——
Aliquots	38	0.97	V_a	——
		B. Borings at One Position		
Borings	5	51.37	$V_a+2V_s+4V_b$	——
Subsamples	6	15.00	V_a+2V_s	——
Aliquots	12	0.42	V_a	——
		C. Sub-samples of Large Composite		
Subsamples	9	4.05	V_a+2V_s	——
Aliquots	10	0.65	V_a	——
		D. Pooled Analysis		
Positions	19	61.78	$V_a+2V_s+4(V_b+V_p)$	2.60
Borings	5	51.37	$V_a+2V_s+4V_b$	11.10
Subsamples	34	6.95	V_a+2V_s	3.07
Aliquots	62	0.81	V_a	0.81
		Nonuniform Area		
Positions	19	251.87	$V_s+4(V_b+V_p)$	110.80
Borings	5	30.28	V_s+2V_b	14.40
Subsamples	31	1.49	V_s	1.49

*V_a, V_s, V_b, and V_p represent true variance associated with aliquots, subsamples, borings, and positions, respectively.

COMPARISON OF UNIFORM AND NONUNIFORM AREAS

The individual phosphorus determinations are recorded in Table 2 and the pooled analysis for the nonuniform area is shown in the lower portion of Table 3. Chemical analyses were made first on samples from the uniform area. An examination of the results indicated that the variation in laboratory technique, as measured by "aliquots"

TABLE 4.—*Individual determinations of exchangeable calcium and potassium (ppm) from uniform and nonuniform areas.*

	Calcium, Uniform area, Subsamples 1	Calcium, Uniform area, Subsamples 2	Calcium, Nonuniform area, Subsamples 1	Calcium, Nonuniform area, Subsamples 2	Potassium, Uniform area, Subsamples 1	Potassium, Uniform area, Subsamples 2	Potassium, Nonuniform area, Subsamples 1	Potassium, Nonuniform area, Subsamples 2
Positions								
1	240	220	340	330	59	58	19	18
2	380	350	340	340	50	43	16	18
3	310	340	230	250	48	47	26	23
4	280	310	450	460	51	50	16	16
5	280	310	450	450	58	52	64	67
6	280	280	510	540	51	51	40	37
7	310	340	430	450	72	80	52	50
8	310	340	380	500	64	55	18	19
9	230	250	400	410	57	52	24	25
10	340	340	340	370	46	52	41	41
11	280	310	430	430	55	58	17	17
12	230	230	400	430	55	48	33	35
13	230	250	480	500	62	57	59	57
14	310	310	600	570	64	64	43	42
15	230	240	450	450	50	57	48	52
16	340	340	540	530	66	64	68	74
17	280	300	570	570	52	55	45	46
18	260	270	540	510	51	52	54	56
19	310	310	430	400	56	50	46	57
20	280	300	430	440	47	52	43	42
Borings								
1A	230	220	360	390	48	40	13	13
1B	250	220	380	370	65	59	18	18
1C	250	250	360	380	64	54	9	8
1D	190	200	270	270	69	66	19	24
1E	210	200	330	340	53	49	28	28
1F	280	280	280	280	56	58	—	—
Subsamples of "Bulk Sample"								
	310	330	330	—	64	56	18	—
	310	310	320	—	56	58	18	—
	340	330	340	—	60	62	19	—
	340	340	340	—	61	57	19	—
	330	310	310	—	64	63	19	—

was so small in comparison to other sources that it was not considered necessary to obtain an independent estimate of this variation in later analyses. A comparison of the phosphorus results from the two areas is interesting. Subsampling of the soils from the uniform area seemed to be more variable, although there is no apparent reason for this. The variation between positions is considerably greater in the nonuniform areas as would be expected. As pointed out above, little significance can be attached to a comparison of the two estimates of "boring" variation because of the manner in which the samples were obtained.

The individual calcium and potassium determinations are given in Table 4 and the pooled analyses of variance are shown in Table 5. The calcium data are similar to phosphorus in that the variation between positions is much greater in the nonuniform area. Estimates of subsampling variation agree very well in the two areas. On potassium the mean square for borings in the uniform area was slightly larger than that for positions, indicating that there is very little variation in potassium content other than that found within small areas. The variance for subsamples is again larger for the uniform area. There was a slight heterogeneity of the three components making up the pooled subsample estimate, but there is no apparent reason for this.

TABLE 5.—*Pooled analyses of variance of calcium and potassium determinations for the uniform and nonuniform areas.*

Source of variation	Calcium			Potassium		
	d.f.	M.S.	Estimated true variance	d.f.	M.S.	Estimated true variance
Uniform Area						
Positions	19	3,273	680	19	99.02	——
Borings	5	1,913	864	5	134.37	60.84
Subsamples	35	186	186	35	12.68	12.68
Nonuniform Area						
Positions	19	14,454	4,893	19	590.95	239.72
Borings	5	4,668	2,248	5	111.52	53.56
Subsamples	30	173	173	29	4.40	4.40

The organic matter and pH data are given in Table 6 and the analyses of variance in Table 7. In contrast to the other properties, there was quite a difference in the average organic matter content of the two areas. However, there was very little difference in the variation between positions in the two fields. The larger sub-sampling error in the samples from the uniform area may have a reasonable explanation in the case of organic matter. Lespedeza was growing on the field at the time of sampling so that small fragments of roots were included in the samples. This type of organic matter would be more difficult to distribute evenly throughout the sub-samples than

TABLE 6.—*Individual determinations of percentage organic matter and pH in samples from uniform and nonuniform areas.*

	Organic matter				pH		
	Uniform area		Nonuniform area		Uniform area	Nonuniform area	
	Subsamples		Subsamples		Subsample	Subsamples	
	1	2	1	2	1	1	2
Position							
1	1.70	1.86	0.72	0.76	5.3	5.9	5.6
2	2.34	2.17	0.74	0.76	5.2	4.9	4.9
3	2.16	2.14	1.00	1.08	5.3	5.0	4.9
4	1.76	1.70	0.88	0.86	5.2	5.5	5.5
5	2.26	2.10	1.32	1.24	5.3	5.3	5.2
6	1.85	1.82	0.94	0.92	5.4	5.6	5.6
7	2.24	2.01	0.90	0.92	5.4	5.4	5.4
8	2.16	2.19	0.86	0.80	5.4	5.2	5.3
9	2.08	2.04	0.72	0.70	5.2	5.1	5.2
10	1.92	1.92	0.88	0.74	5.3	5.4	5.4
11	1.76	1.70	0.74	0.80	5.3	5.5	5.4
12	2.00	1.87	0.78	0.76	5.4	4.8	4.8
13	2.12	2.12	1.28	1.36	5.3	5.6	5.6
14	2.25	2.21	0.88	0.96	5.4	5.4	5.4
15	2.22	2.40	0.78	0.78	5.3	5.0	5.0
16	2.58	2.32	1.08	1.02	5.3	5.0	5.1
17	1.98	2.18	0.90	0.94	5.3	5.0	5.1
18	2.08	2.02	0.80	0.82	5.3	5.2	5.4
19	2.22	1.95	0.94	1.02	5.3	4.9	4.9
20	2.16	2.09	1.00	0.98	5.3	5.1	5.3
Borings							
1A	1.88	1.66	0.80	0.86	5.3	5.6	5.6
1B	1.78	1.76	0.70	0.72	5.4	5.6	5.5
1C	1.78	1.84	0.82	0.82	5.2	5.5	5.5
1D	1.92	1.98	0.74	0.72	5.3	5.6	5.5
1E	1.70	1.74	0.82	0.82	5.2	5.3	5.3
1F	1.87	1.90	0.68	0.70	5.2	5.4	5.4
Subsamples of "Bulk Sample"							
	1.90	1.90	0.50	—	5.2	4.9	—
	1.76	1.93	0.48	—	5.1	4.8	—
	1.90	1.90	0.46	—	5.2	4.8	—
	1.94	1.94	0.52	—	5.2	4.7	—
	1.86	1.92	0.48	—	5.2	4.9	—
	—	—	—	—	5.2	—	—
	—	—	—	—	5.1	—	—
	—	—	—	—	5.2	—	—
	—	—	—	—	5.2	—	—
	—	—	—	—	5.2	—	—

the humuslike material from the fallow, nonuniform area. Determinations of pH for the uniform area were made on only one sub-sample from each boring and therefore the estimate of sub-sampling varia-

tion is based on only the 10 readings from the "bulk sample". This accounts for the difference in degrees of freedom for the two subsampling mean squares, and also explains the difference in computation of the true variances. The variation between positions in the uniform area is again very small and there seems to be no major variations across the field with respect to this property.

DISCUSSION

The primary objective of this study was to develop a basis for evaluating a sampling procedure for soils of different degrees of variability. From a knowledge of the contribution to the total variation that is made by each of the several sources, the accuracy ($V_{\bar{x}}$) of any particular sampling scheme can be predicted as indicated above. In practice a sample would be drawn from an area usually with the object of determining several of its properties from a single composite. Each property may have a different pattern of variation in the field as has been illustrated. Also the level of accuracy desired for each property may vary considerably. However, the number of positions to be sampled will be determined by the property requiring the greatest intensity of sampling.

Tables 8 and 9 have been prepared to indicate the approach for determining the sampling procedure for the five properties discussed above. The "limits of accuracy" were chosen arbitrarily to cover the range of accuracy usually desired in soil analyses, and the values used represent the 5% fiducial limits, expressed as $s_{\bar{x}}t_{.05}$, in which $s_{\bar{x}} = \sqrt{V_{\bar{x}}}$ is the standard error of the mean and $t_{.05}$ is the t value with a probability of 0.05. No method has been devised for determining the proper degrees of freedom to use under these conditions; so the *t* value arbitrarily chosen was that associated with the smallest degrees of freedom used in estimating the true variances, exclusive of borings. In determining the number of field positions and subsamples necessary to measure the phosphorus content to within 9 ppm of the true field mean, the equation for the variance of the mean is set equal

TABLE 7.—*Pooled analyses of variance of organic matter and pH determinations on samples from the uniform and nonuniform areas.*

Source of variation	Organic matter			pH		
	d.f.	M.S.	Estimated true variance	d.f.	M.S.	Estimated true variance
			Uniform Area			
Positions........	19	0.0715	0.0285	19	0.0032	———
Borings.........	5	0.0145	0.0040	5	0.0044	0.0029
Subsamples......	35	0.0065	0.0065	9	0.0015	0.0015
			Nonuniform Area			
Positions........	19	0.0560	0.0240	19	0.1431	0.0586
Borings.........	5	0.0081	0.0034	5	0.0260	0.0103
Subsamples......	30	0.0013	0.0013	30	0.0053	0.0053

to $\frac{(9)^2}{(t)}$. In Table 8 is given the number of positions required to attain specified levels of accuracy when one and two subsamples are analyzed.

TABLE 8.—*Number of positions required to attain specified limits of accuracy for phosphorus, calcium, potassium, organic matter, and pH in uniform and nonuniform areas.*

Limit of accuracy*	Number of positions required			
	Uniform area		Nonuniform area	
	1 subsample	2 subsamples	1 subsample	2 subsamples
	Phosphorus			
3 ppm	Impossible	120	224	96
6 ppm	4	2	19	17
9 ppm	1	1	8	7
	Calcium			
25 ppm	Impossible	31	Impossible	125
50 ppm	4	4	17	15
75 ppm	2	2	7	6
	Potassium			
6 ppm	Impossible	33	77	49
9 ppm	11	5	21	18
12 ppm	3	3	11	10
	Organic Matter			
0.1%	Impossible	Impossible	28	18
0.2%	13	6	4	4
0.3%	3	2	2	2
	pH			
0.1 pH	7	3	Impossible	Impossible
0.2 pH	1	1	18	11
0.3 pH	1	1	5	4

*Amount that must be added to and subtracted from a sample average to obtain a range having a 0.95 probability including the true field average.

It will be noted that in many instances the desired accuracy cannot be obtained by analyzing only one or two subsamples regardless of the accuracy of field sampling. A case in point is the measurement of phosphorus in a uniform field to within 3 ppm of the true mean. The equation is $\frac{2.60+11.10}{p}+\frac{3.07+0.81}{s}=\left(\frac{3}{2.09}\right)^2$. Even if the position and boring variance, $\left(\frac{2.60+11.10}{p}\right)$, were reduced to zero, two subsamples would not be enough to reduce the subsampling variance

TABLE 9.—*Number of subsamples required to give indicated limit of accuracy when 10 and 30 positions were taken in the field.*

Limit of accuracy	Uniform area		Nonuniform area	
	10 positions	30 positions	10 positions	30 positions
		Phosphorus		
3 ppm	6	3	Impossible	Impossible
6 ppm	0.6	0.5	Impossible	80.4
9 ppm	0.2	0.2	0.3	0.1
		Calcium		
25 ppm	Impossible	2	Impossible	Impossible
50 ppm	0.4	0.4	Impossible	0.5
75 ppm	0.2	0.2	0.3	0.2
		Potassium		
6 ppm	6	2	Impossible	Impossible
9 ppm	1	0.8	Impossible	0.5
12 ppm	0.5	0.4	2	0.2
		Organic Matter		
0.1%	Impossible	6	Impossible	0.9
0.2%	2	0.8	0.2	0.2
0.3%	0.4	0.3	0.1	0.1
		pH		
0.1 pH	0.9	0.8	Impossible	Impossible
0.2 pH	0.2	0.2	3	0.8
0.3 pH	0.1	0.1	0.4	0.3

by the required amount. If the investigator desired to attain such a degree of accuracy he would have to improve the precision of the laboratory technique either by refining the procedures or by making determinations on more subsamples from the composite.

In preparing Table 8 it was assumed that the accuracy of subsampling would be unaffected by the number of samples in the composite. However, theoretically the subsampling error would increase with increasing volume of the composite sample. For practical purposes this increase is probably insignificant except when the composite becomes so large as to require subsampling in the field. Field subsampling involves hand mixing in containers that are often inadequate and where there are no facilities for reducing particle size. By taking proper precautions it is possible that a sample can be sufficiently well mixed to allow an accurate drawing of a 50% subsample in the field. Quart containers are commonly used for soil samples by the North Carolina Experiment Station. Under these conditions it is questionable whether it is safe to assume a negligible increase in subsampling error if the number of positions required will yield a quantity of soil in excess of 2 to 3 quarts. Thus in the table, any limit of accuracy requiring more than about 30 positions may well be classed with those marked impossible for practical purposes.

There is little likelihood of desiring to draw a sample of fewer than about 10 positions from any area unless the sample is drawn for the determination of one rather uniform property such as pH. Therefore, 10 and 30 positions per sample were considered as extremes in practice in areas of this size. Table 9 has been prepared to indicate the effect of subsampling and laboratory technique when a composite of 10 or 30 positions was taken in the field. Again the procedure may be illustrated with phosphorus from the uniform area, the formula being $\frac{2.60+11.10}{10}+\frac{3.07+0.81}{n}=V_{\bar{x}}$. Solving for n for the different limits of accuracy will indicate the number of subsamples (or other reduction in laboratory variation) necessary to achieve the desired results.

In the case of phosphorus from the uniform soil area, six subsamples would be required to reduce the laboratory variation to a point where the mean of 10 positions would be within 3 ppm of the true mean.

The combinations in the table marked "impossible" indicate that the field variation is too great to permit such accuracy with that number of positions. In such cases it is the field rather than laboratory variation that limits the improvement of the technique.

On the other hand, if it were necessary to measure phosphorus only to within 9 ppm, and a composite sample of 10 borings were drawn, the laboratory technique would not need to be as accurate as that used in these studies. The values less than unity in Table 9 indicate that greater precision was achieved in the laboratory than was necessary for the specified limit of accuracy. This means that the extra effort used in such cases would be an over-refinement and therefore inefficient. It is quite conceivable, for example, that for purposes of making fertilizer recommendations, a limit of accuracy of 9 ppm of phosphorus would be sufficiently precise. The frequent sharp fall in the required number of subsamples from "impossible" to less than one is a further indication that field sampling rather than laboratory technique is imposing a limit on the success of the sampling procedure.

For a given level of accuracy of a particular composite both field and laboratory variation must be controlled. Tables 8 and 9 indicate the limits within which each source of variation must come. In order to attain a certain degree of precision there is a minimum number of positions required and also a maximum amount of laboratory variation allowable. The most efficient sampling procedure must be set up within these limits. For example, in order to measure phosphorus from a uniform area to within 3 ppm, a laboratory technique must be perfected to give precision equivalent to five to nine subsamples of the technique used here, and 10 to 30 positions must be taken in the field. To measure organic matter in a nonuniform area to within 0.1% fewer than 30 borings would be required.

The above discussion has been based on field variation observed within areas approximately ¾ acre in size where it was observed that stratification had no effect. However, it would not be safe to assume

that such would be the case in larger areas. Therefore, more study is required before these data can be expanded to fields several acres in size, or of different fertility patterns.

Finally, the limitations of the fields studied are recognized. Further work is in progress in other areas which will extend the studies to other soil types and to fields which have been variously fertilized and limed.

SUMMARY

A study was made of soil sampling from a field which was uniform and from one which was quite variable in appearance and soil type. Individual samples of the surface soil were taken at 20 equally spaced positions in each field. Determinations were made of readily soluble phosphorus, exchangeable potassium and calcium, easily oxidizable organic matter, and pH on each sample. Studies were made of analyses of duplicate subsamples of each individual sample and duplicate aliquots where extraction was involved.

Attempts are made to isolate and measure (a) variations in the individual samples from the area to be characterized, (b) variations in subsampling the individual samples drawn from the area, (c) variations accompanying the analytical procedure. Data are presented to illustrate the number of positions required to attain specified limits of accuracy for the various properties studied, and to illustrate the number of subsamples required to give various limits of accuracy when 10 and 30 positions were taken in the field.

The properties studied had different patterns of variation. Where several properties are concerned, the field and laboratory precision necessary will be determined by the level of accuracy desired for each property and by the property requiring the greatest intensity of sampling. Results from the nonuniform field in particular indicate that often greater precision is being used in the laboratory than is necessary, since field variation is such that it is the limiting factor, even though a reasonable number of positions are taken. Under such conditions refinement of laboratory methods would appear to be inefficient.

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Interspecific and Intergeneric Hybridization in Forage Crop Improvement[1]

R. Merton Love[2]

SPECIES and genera are delimitations of populations and groups of populations set up by the taxonomist. Rarely have cytological and genetic studies played an important part in his deliberations. This is not meant to cast any reflections on the systematist, for cytogenetic studies are time-consuming and it is hardly to be expected that the systematic botanist would delay the classification of plants until the pertinent cytogenetic data were forthcoming. Nevertheless, anyone interested in the improvement of forage crops, and particularly the uncultivated grasses, must realize that the delimitations of populations set by the systematist do not always provide an accurate index of the potential hybridization possibilities of the material.

CYTOGENETIC STUDIES

When the plant breeder contemplates hybridization, cytogenetic studies can be of great assistance in a number of ways. Of first importance is a study of chromosome number and behavior in the parents themselves. For instance, at the beginning of the Stipa improvement program in California, many seed collections of *Stipa pulchra* Hitchc. were made. Many of these collections were labeled "slender type". A routine cytological examination showed that all the "slender type" plants had $n=35$, $2n=70$ chromosomes, whereas typical *S. pulchra* plants had $n=32$, $2n=64$ (10)[3]. A knowledge of these chromosome numbers threw into a new light the fact that typical *S. pulchra* and the "slender type" had been found growing together in a number of sites. A search for hybrids in one locality was successful. (They have since been found elsewhere and also made artificially.) They were intermediate in most respects, they had the intermediate chromosome number ($2n=67$), and they were invariably sterile. Furthermore, meiotic studies showed that they had few chromosomes in common—a maximum of 19. As a result of these studies the "slender type" was set apart from *S. pulchra* and is now called *S. cernua* (11). In other words, it is not a strain or line of *S. pulchra* and cannot be expected to contribute to strain crossing with desirable selections of *S. pulchra*. A cytological study of a taxonomic species was very helpful in this instance in contributing to a better understanding of the delimitations of the species in question.

Again, on the contrary, the frequent occurrence of intergeneric hybrids has indicated that the generic lines in many grasses have not been too well drawn. In some tribes there is little correlation between

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[3]Numbers in parenthesis refer to "Literature Cited", p. 46.

taxonomic "genera" and hybridization possibilities. This has been very well demonstrated by Stebbins and co-workers (12) for some genera of the tribe Hordeae. As a result of their studies on the cytological relationships between parental species, they concluded: "When compared with species of *Aegilops*, therefore, *Elymus glaucus*, *Sitanian jubatum*, *S. hystrix*, *Agropyron Parishii* and *A. pauciflorum* behave cytogenetically as if they belong to the same section or subgenus rather than to different genera. The cytogenetic evidence, therefore, would suggest that a drastic revision of the present systematic treatment of the tribe Hordeae is necessary, but the nature of this revision will not be clear until many more hybrids have been studied."

A very simple method of investigating meiotic stability in the parental strains is an examination of young pollen quartets or tetrads. In most species that behave cytologically and genetically as diploids, bivalent formation is the rule. However, in polyploids of this type, such as varieties of *Triticum aestivum* (7) and strains of *Stipa cernua*, there is usually a small percentage of pollen quartets with micronuclei, the micronuclei consisting of one or more chromosomes that failed to be incorporated in the young pollen nuclei. Any plant in a strain that has a higher percentage of irregular quartets than the mean should not be used as a parent in crosses. Because of chromosome losses, Mendelian segregation cannot be expected in the offspring. In fact, it has also been shown that unpaired chromosomes are a source of chromosome breakage through misdivision during meiosis (3). This may be because the unpaired chromosome is not adjusted to the "timing" of the various phases of meiosis so that accidents occur. Such plants, and their progeny, may be useful for cytogenetic studies and may provide valuable information on the cytogenetic constitution of the species, but they would handicap a hybridization program.

Cytogenetic studies *per se* are useful. Crossing two possible parent species with a third may provide more information on the chromosomal differences in the two parents than crosses involving the two parents alone. Some data from *Stipa* hybrids will be mentioned briefly. Details will be published separately. In a study of F_1 *Stipa cernua* × *S. pulchra* ($2n=67$), it was found that 18% of the 50 pollen mother cells examined had 14 pairs and 39 univalents, 21% had 16 pairs and 35 univalents, and 21% had 17 pairs and 33 univalents. The remaining 40% had from 10 to 19 pairs. When the *S. cernua* × *S. lepida* F_1 ($2n=52$) was examined, 22% of the pollen mother cells had 17 pairs and 18 univalents, and 18% had 2 chains of 3 chromosomes, 15 pairs, and 16 univalents. Synapsis in the remainder of the 50 cells examined varied from 14 to 17 pairs. However, when the *S. lepida* × *S. pulchra* F_1 ($2n=49$) was examined, it was found that 69% of the pollen mother cells had 17 pairs and 15 univalents.

A spontaneous haploid of *S. cernua* had a maximum of two loose pairs (4) and this duplication in chromosomal segments of *S. cernua* possibly contributes to the results obtained in its hybrids. Nevertheless, it may be concluded that the species *cernua* and *pulchra* differ in two ways; (a) the parental species other than *lepida* involved in

the crosses that gave rise to these highly polyploid species; and (b) *pulchra* probably has the original *lepida* chromosome set relatively unchanged, whereas this 17-chromosome set in *cernua* has undergone some changes. In other words, if *lepida* (n = 17) is represented as AA, then *pulchra* (n = 32) is AA BB, and *cernua* (n = 35) is A_1A_1 CC.

USE OF WIDE CROSSES

STERILE HYBRIDS

These and other interspecific hybrids of *Stipa* are both male and female sterile but doubling the chromosome number results in varying degrees of fertility. This use of hybrids will be discussed later. However, hybrid vigor may be utilized in the sterile hybrids themselves. This may be very important in forage grasses since the hybrids are long-lived perennials and cross pollination is common so that natural hybrids are readily produced. The corn breeders have been very successful in their efforts to utilize hybrid vigor. The techniques differ considerably when applied to *Stipa* species, but the results show promise of being just as spectacular.

Wherever the ranges of *Stipa* species overlap, hybridization occurs naturally and the hybrids readily establish themselves in the field (5). In spite of the frequency of natural crossing, selection work at Davis has shown that vigorous lines can be obtained by inbreeding and strains differing in a number of characteristics are readily purified. Replicated plots (12×16 feet) were seeded broadcast at Davis in December, 1942, using three strains of *cernua*, three of *pulchra*, and one of *lepida*. The plots were separated by 4-foot alleys. All strains were cleistogamous in 1943 so that seed set that year was selfed and volunteers arose from that selfed seed. (First year seed on these species is always cleistogamous at Davis.) In the spring of 1944 there was ample opportunity for cross pollination between plots, since the stigmas were wrapped around the empty glumes before the anthers in the same floret were extruded. Seeds that shattered in May, 1944, germinated in November that same year. In 1945, from 0 to 19 interspecific hybrids were found in some plots. These remained green a month to 6 weeks longer than the parental species in the spring of 1945, and turned green before the parents in October, 1945.

In November 1945, a series of plots was seeded to various strains of a number of *Stipa* species, using two species to a plot, in order to obtain a measure of the crossability of the different strains. In 1948 a preliminary estimate can be made of the strains that hybridize readily. Then, strains of the two species that are highly compatible will be seeded on the range. The strains used are hardy and drought resistant. Their first generation hybrids can be expected to show hybrid vigor in these respects, and since the hybrids are completely sterile there will be no breakdown of this hybrid vigor, of which one important characteristic is increased vegetative growth.

The use of hybrid vigor in sterile species hybrids, then, is the increase in length of grazing season as well as increased forage production. In contrast to the hybrid corn program, the *Stipa* hybrids will

be produced naturally *in situ* and not artificially at the Experiment Station.

AMPHIDIPLOIDS

In general, it has been shown that the less pairing there is in the hybrid, the more successful is the fertile plant resulting from colchicine treatment (2). Even slight differences may be important as indicated recently by W. K. Pope (unpublished) on the colchicine treatment of the hybrid *Triticum durum* var. Mindum ($2n=28$)× *Agropyron trichophorum* ($2n=42$). Two F_1 plants of this cross were used. One had 0 to 4 loose pairs with a mean of 1.60; the other had 3 to 10 pairs with a mean of 6.06. When multivalent formation is taken into account the difference is even more striking. The first had 0 to 8 chromosomes per cell synapsed, the mean being 3.20, whereas the second had 8 to 23 synapsed chromosomes per cell, the average being 14.78 (6). Mr. Pope applied colchicine to 25 clonal divisions of each hybrid and more amphidiploid sectors were obtained from the plant with the smaller, almost negligible, amount of chromosome pairing. Furthermore, the amphidiploid sectors from the hybrid with 6.06 synapsed chromosomes were 80% fertile, whereas those from the hybrid with 14.78 synapsed chromosomes were only 40% fertile.

According to the classical concept of plant evolution through species or intergeneric hybridization, amphidiploidy has played an important role in the production of new species and this idea has carried over into the thinking and planning of the plant breeder. His procedure has been to produce a sterile species hybrid that is vigorous, double the chromosome number, and so obtain the amphidiploid with "fixed" hybrid vigor. Although in actual practice this has not yet been very helpful, the potentialities are great. There is evidence that different strains of one species react differently with those of another, and so the plant breeder must think in terms of wide crosses involving certain *strains* of species. One method would then be to make a large number of interspecific strain crosses and produce their amphidiploids. Out of the many possible interspecific strain crosses a few desirable nonsegregating amphidiploids might be obtained. This would certainly be the neatest way of improving the forage crop.

A second method would be to use the related nonsegregating amphidiploids themselves in a hybridization program, crossing amphidiploid 1 with amphidiploid 2 and 3 and 4, and so on. Hybridization at the amphidiploid level would serve as a means of combining desirable gene blocks from the different species used. A selection program on such material should lead to great improvement of the forage crop.

Then there is a third way the amphidiploids may be used. It appears that many amphidiploids do not breed true. Even in the amphidiploids from crosses at the diploid level in the Triticinae, Sears (8, 9) obtained only 1 out of 18 that showed some promise of remaining constant. And at the higher ployploid level, in some groups at least, as Armstrong and his co-workers have shown (1), most of the so-called amphidiploids segregate. This allows the plant breeder to do his selecting among a wide range of types, including variations in fertility, longevity, vegetative vigor, seed size, habit, range of adaptation, and so on.

NATURAL FERTILE DERIVATIVES FROM SPECIES HYBRIDS

Work on the Agropyron×wheat hybrids indicates a third use of wide crosses. Fertile derivatives have been obtained both naturally (7) and artificially (Pope, unpublished). It is likely that those occurring naturally owe their origin to the fortuitous union of viable, compatible gametes. These gametes may be unreduced or partially reduced, but at this $5\times(F_1)$ level of chromosome number the viable gametes must have multiples of chromosome sets. When the fertile derivative with $8\times$ or more chromosomes is obtained (according to this material), the addition or subtraction of individual chromosomes does not necessarily lead to inviability. From these fertile derivatives vigorous plants have been obtained with chromosome numbers varying from 60 to 74.

In hybrids and hybrid material such as this, there is ample opportunity for cross pollination and this adds to the opportunity for selection among fortuitous combinations.

CONCLUSION

The use of hybrids, partially or completely sterile, and their fertile derivatives in a plant improvement program is in its infancy. So far, it has been a plaything in the hands of the cytogeneticist. Its possibilities in forage crops improvement warrant the development of a well-organized program, especially on the unselected material in native species now coming to the fore.

SUMMARY

1. Cytogenetic studies are a useful tool in the improvement of forage crops (a) in helping to delimit species, (b) in selecting meiotically stable parental material and derivatives of wide crosses by the use of pollen quartet studies, and (c) in providing information on the species hybrids themselves.

2. Interspecific and intergeneric hybrids are potentially valuable in the improvement of forage crops in three ways, as follows:

A. Sterile hybrids themselves may be useful as the *Stipa* material indicates. Natural cross pollination between species and ease of establishment of the hybrids is helpful.

B. The amphidiploids may be used in three ways depending on the nature of the amphidiploid.

   a. Nonsegregating amphidiploids—an end in themselves.
   b. Hybridization of related nonsegregating amphidiploids, followed by selection.
   c. Selection in progeny from amphidiploids that do not breed true.

C. Fertile derivatives produced by natural crossing of the nearly sterile hybrids may or may not have the amphidiploid chromosome number, but in any event, they would be used in the same way as the segregating amphidiploids mentioned above.

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Inheritance of Curly Top Disease Reaction in the Bean, *Phaseolus vulgaris*[1]

Herman K. Schultz and Leslie L. Dean[2]

LITTLE published information is available on the inheritance of resistance in beans to the curly top virus. A knowledge of the mode of inheritance of disease reaction is essential in the development of a logical bean-breeding program for disease resistance. It seems worthwhile to summarize and record at present such information as has been accumulated by the Idaho Agricultural Experiment Station even though more work on inheritance appears necessary. The many data obtained from breeding studies on the development of curly top resistant varieties and from a special genetic study are indicative of the mode of inheritance of curly top disease reaction for certain bean varieties.

Bean breeding and testing programs have given much emphasis to the sugar beet curly top disease since its importance in bean production was emphasized in 1926 (1).[3] Sugar beet researches had already established curly top as a virus disease and its relationship to the beet leafhopper. Breeding for curly top disease resistance in sugar beet varieties (2, 3, 6, 11, 12) was more difficult than in beans (5, 8, 9, 13, 14, 15) because the sugar beet is a naturally cross-pollinated plant usually necessitating the employment of some sort of inbreeding to obtain homozygous resistant stocks, while the bean is a naturally self-pollinated plant. Also, highly resistant and desirable sugar beet strains were not readily available, while in beans Red Mexican, a resistant variety, was immediately at hand.

Host plants of curly top include tomatoes, squash, and other vegetables, as well as numerous species of wild mustards and Russian thistle (4, 16, 17, 18, 20). Along with the nearness of susceptible hosts, time of planting, location of bean growing areas, and other physical factors were studied for the control of curly top (7, 8, 9, 10, 20) as an aid to western bean production. Breeding for disease resistance through hybridization appeared to be the logical approach to the program of control (15, 19). The data for the analysis of the mode of inheritance of disease reaction reported here were obtained from several bean-breeding studies carried out over a period of years in southern Idaho.

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[2]Associate Agronomist and Associate Plant Pathologist, respectively. The authors wish to acknowledge the contributions made by Mr. Donald M. Murphy and Dr. Walter H. Pierce, both formerly with the Idaho bean improvement program for the collection and summarization of data for the earlier studies given in Table 1; also, Dr. C. W. Hungerford, Plant Pathologist and Vice Director, Dr. Glenn KenKnight and Prof. J. M. Raeder, Associate Pathologists, for their assistance in the field in reading of curly top disease symptoms and other phases of field work.

[3]Figures in parenthesis refer to "Literature Cited", p. 51.

PARENT VARIETIES AND PROGENIES

A group of 74 F_3 progenies of Red Kidney×Great Northern U. I. 15 and their parents were grown in 1945 at the Idaho Branch Experiment Station at Caldwell, Idaho, for curly top disease reaction readings. The Red Kidney parent was a selected single plant progeny used as the curly top susceptible parent. The Great Northern U. I. 15 parent was also a pure line selected from the original Great Northern U. I. 15 variety and used here as the source of disease resistance. The F_1 and F_2 generations were grown in northern Idaho under curly top free conditions.

The number of plants per F_3 progeny ranged from 10 to 84 with an average of 39 individuals. All beans were planted in hills (two seeds per hill) 1 foot apart with the rows 3 feet apart. As checks, about 475 plants of each of the two parents were grown in rows distributed throughout the bean plots. Also, two dozen tomato plants were placed uniformly over the disease plot to reveal further the distribution and prevalence of the disease, and to attract the beet leafhopper, *Eutettix tenellus* Baker, the curly top insect vector.

In 1944, a similar group of F_3 progenies, Red Kidney×Great Northern U. I. 15, 190 total, were planted on the regular bean-testing plot at Buhl, in the important bean-growing area in south central Idaho, for a study of curly top segregation. These hybrid progenies and their parents were planted in 3-foot rows, with plants spaced about 1 foot apart. Stands obtained were generally poor with about 30% of the progenies lost.

Curly top disease studies were made in 1937, 1938, and 1940 on F_1 and F_2 crosses between the varieties Common Red Mexican, resistant, and Dark Red Kidney, susceptible; and between Burtner, resistant, and Dark Red Kidney, susceptible. Crosses between Bountiful, a curly top susceptible variety, and the two aforementioned resistant varieties were studied also. All tests for infection were made under field conditions on the bean-testing plot at Buhl.

Bean plants infected by the curly top virus during the early seedling stage of development usually became chlorotic and died. Plants not attacked until they were nearly full grown usually survived until the end of the season. In these studies, plants classified as susceptible were individuals exhibiting typical curly top disease symptoms regardless of the degree of severity, which often ranged widely. It was sometimes extremely difficult to distinguish the curly top disease symptoms when certain other bean diseases were present also.

The data from the various year-by-year studies are presented separately. They were analyzed as individual studies and finally analyzed as a composite group. Genetic interpretations are made on the basis of the grouped data analysis.

CURLY TOP DISEASE DATA

Two independent disease readings were made on the F_3 progenies and parents grown in 1945 at Caldwell. The Great Northern U. I. 15 or resistant parent was 100% curly top free, while Red Kidney, the susceptible parent, showed 12 disease-free plants out of 471, or about 98% diseased. The two dozen tomato check plants were heavily attacked, with no escape and one-half of them killed.

Based on the combined disease readings made in 1945, the 74 F_3 progenies were classified as follows: 29 resistant, 40 segregating, and 5 susceptible. The 29 progenies classed as resistant contained no plants showing distinct curly top disease symptoms. The five progenies designated as susceptible contained some curly top free bean plants. One of these five progenies, a 30-plant progeny, was 100% attacked. Those 40 progenies classified as segregating contained plants, the majority of which, were curly top free. Here the resistance ranged from 60 to 98% of the plants per progeny.

The 190 F_3 progenies and parents grown in 1944 at Buhl resulted in a poor test because of a light curly top epiphytotic. The Great Northern U. I. 15 parent was again 100% disease free, while the Red

Kidney parent contained 39% of curly top free plants. Lack of curly top spread, together with poor initial stands following wet soil conditions, made the test of little value. Out of 139 progenies, 85 contained all curly top free plants, 36 contained some diseased plants, and 8 progenies contained plants most of which were attacked by the curly top virus.

The curly top disease data obtained in 1937, 1938, and 1940 on crosses of the resistant parents, Red Mexican and Burtner with the susceptible parents, Dark Red Kidney and Bountiful, and on the parent varieties will be presented as a composite group. All F_1 generation plants were field grown under curly top virus exposure. Out of 52 F_1 individuals of Dark Red Kidney crossed with Red Mexican and Burtner and reciprocal, 5 plants were heavily attacked by curly top. The resistant ones or balance of the F_1 plants were checked and found to be true F_1's on the basis of seed color characters. The five plants which succumbed very likely were from seeds of unsuccessful crosses when Red Kidney was used as the maternal parent.

Similar results were obtained from F_1 crosses between Bountiful and Red Mexican and Burtner. The F_1 crosses between the two susceptible parents, Bountiful and Dark Red Kidney, resulted in all susceptible offspring while the crosses between the two resistant parents, Red Mexican and Burtner, yielded all resistant F_1 plants. Parental variety reactions were 100% resistant for the two resistant varieties, about 2% of escaped plants for the susceptible variety Dark Red Kidney, and less than 5% of curly top free plants for the Bountiful variety.

The F_2 progenies were composed of bulked F_1 lots from each of the above variety crosses. The number of curly top resistant and susceptible plants observed in these segregating populations are recorded in Table 1.

TABLE 1.—*Curly top disease reaction classification of F_2 populations of four bean variety crosses and their parents.**

Crosses and parents	Number of bean plants classed as		
	Resistant	Susceptible	Total
Red Mexican×Dark Red Kidney	699	111	810
Red Mexican×Bountiful	628	144	772
Burtner×Dark Red Kidney	1,038	146	1,184
Burtner×Bountiful	614	161	775
Red Mexican, parent variety	1,397	0	1,397
Burtner, parent variety	1,225	0	1,225
Dark Red Kidney, parent variety	51	659	710
Bountiful, parent variety	11	1,152	1,163

*Data obtained in 1937, 1938, and 1940 and summarized by Donald M. Murphy.

GENETIC ANALYSIS OF DISEASE REACTION

The above data give evidence that curly top resistance is dominant and susceptibility recessive. This is indicated by the resistant behavior of the F_1 hybrids, by the preponderance of resistant indi-

viduals in the F_2 populations, and by the great percentage of F_3 progenies composed mostly of resistant bean plants. The source of resistance was from the three varieties Red Mexican, Great Northern U. I. 15, and Burtner. The Great Northern U. I. 15 variety is a white bean bred for curly top resistance which was obtained from the Red Mexican variety. Burtner's source of resistance is not known.

A simple general explanation of the segregation on a factorial basis for this composite of all data presented is not too readily accomplished. The 1945 F_3 data on 74 progenies were recorded as 29 resistant:40 segregating:5 susceptible. On the hypothesis of dominance of one factor and recessive of another to give resistance, or, the hypothesis of duplicate dominant epistasis, there would be expected identical distributions of F_3 progenies, namely, 32.4 breeding true for resistance, 37 segregating, and 4.6 susceptible. The Chi-square value from this analysis gave a P value of .95 to .50. Because of lack of progeny size, the 40 segregating families were not easily separated into the particular ratio groups that would be expected from the two above-mentioned hypotheses.

The 1944 F_3 data will not be used in the factorial analysis although they did indicate dominance of curly top resistance.

Data grouped in Table 1 for the Dark Red Kidney crosses gave a distribution of 1,737 resistant:257 susceptible plants, or about 87% resistant as compared to the Bountiful crosses which segregated 1,242 resistant to 305 susceptible, or about 80% resistant. If consideration is given to the parental variety check values where 7% of the plants of the Dark Red Kidney variety were curly top free while only 1% of the Bountiful plants were free, then the above disproportion of resistance in the crosses may not be in any disagreement.

These F_2 ratios are not indicative of a simply inherited reaction. As such, these ratios do not appear immediately to be in agreement with the above-mentioned two factor hypotheses either. On the basis of a 7% correction for escapes for the Dark Red Kidney crosses and a 1% correction for the Bountiful crosses (Table 1), there would be obtained in the F_2 ratios of 1615R:379S and 1230R:317S, respectively, for these two groups of crosses. Both of these ratios are in agreement with the 13:3 hypothesis.

On the assumption of duplicate dominant epistasis, true breeding plants may be of three different genotypes, namely, AABB, AAbb, and aaBB and in equal proportions. Consequently, such F_2 ratios as obtained may be expected, provided that the Red Mexican and Burtner varieties are heterogeneous lots of resistant genotypes. The theoretical ratios resulting from such a situation would be 39 resistant:9 susceptible (or 13:3) which is equivalent to the expectation based on the theory of dominance of one factor pair and recessive of another pair to give resistance. It is unfortunate that in the earlier studies the F_2's from each variety cross were from bulked F_1's and could not be studied on an individual progeny basis. The Great Northern U. I. 15 parent used in the later studies was a closely selected type considered to be homogeneous.

While the final settlement of the factorial basis for the inheritance of curly top reaction is not definitely supplied here, the results re-

corded above do indicate what may be expected in a bean improvement program when concerned with the breeding of curly top resistant varieties.

SUMMARY

Resistance to curly top virus disease reaction was dominant in its mode of inheritance. The source of resistance was from three bean varieties, Common Red Mexican, Burtner, and Great Northern U. I. 15. The susceptible varieties used were Red Kidney, Dark Red Kidney, and Bountiful. The accumulated data indicate that two factors in dominant and recessive epistasis may explain the mode of inheritance of curly top reaction.

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Some Effects of 2,4-D, DDT, and Colorado 9 on Root Nodulation in the Common Bean[1]

MERLE G. PAYNE AND JESS L. FULTS[2]

IN the course of testing various hormone-like chemicals for their growth stimulating and weed killing properties, it was observed that bean plants, *Phaseolus vulgaris*, growing in soil previously treated with low concentrations of 2,4–D (2,4–dichlorophenoxy acetic acid) failed to develop bacterial nodules. In areas where legumes are necessary for maintaining soil fertility, a treatment that would depress, inhibit, or increase development of bacterial root nodules would have a far-reaching influence. Therefore this aroused an interest in the determination of how low a concentration would inhibit nodule formation and further suggested that possibly other antibiotics and insecticides such as DDT (1–trichloro–2, 2–bis(p–chlorophenyl)ethane) might have an effect on legume root nodulation.

The recent work of Appleman and Sears[3] has indicated that DDT applied to sand or soil at high concentration (1,000 to 10,000 pounds per acre) depressed root nodulation and average plant height. This has suggested that possibly other materials similiar to DDT in their insecticidal properties might be found which could be used, yet would not interfere with nodulation.

The objectives of this paper have been (1) to determine the lowest concentration at which 2,4–D interferes with nodulation and (2) to determine the effect of DDT and Colorado 9 (1-trichloro-2, 2-bis (p-bromophenyl) ethane)on nodule formation.

MATERIALS AND METHODS

The DDT and Colorado 9 used in this experiment were prepared in the chemistry laboratories of the Colorado Agricultural Experiment Station at Fort Collins, Colo. The compounds were purified by recrystallization with an alcohol-ether mixture (one-fourth ether and three-fourths 95% alcohol) until the DDT melted at a constant temperature of 107° C, and the Colorado 9 melted at 141.5° C. No effort was made to isolate pure isomers of either compound. In the case of DDT, the constant melting point of 107° C represents a stable mixture of isomers, the p,p′ form predominating. This is the effective isomer as far as its insecticidal properties are concerned.[4] The 2,4-D used was J. T. Baker's 2,4-D free acid, lot number 41946.

Six-inch clay pots, each containing 1,650 grams of soil (1 part sand and 3 parts clay-loam) were used. Pots containing the treated soil were prepared by spraying with 15 ml of the solution under test. After drying, the soil from each pot was emptied on a clean sheet of paper, thoroughly mixed, and replaced in the pot. Thereafter eight beans were planted at a depth of 1 inch and the pots were watered. Following germination, the plants were thinned to five plants per pot. The beans

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[2]Associate Chemist and Associate Botanist, respectively.

[3]Appleman, M. D., and Sears, O. H. Effects of DDT upon nodulation of legumes, Jour. Amer. Soc. Agron., 38:545–550. 1946.

[4]Shaw, H. The new insecticides DDT and benzene hexachloride and their significance in agriculture. Jour. Roy. Agr. Soc. England, 106:204–220. 1945.

were planted on January 16, 1946, and harvested 23 days later on February 8, 1946. At the time of harvest five pots of each treatment were examined and data recorded on the number of nodules per plant. The nodules from each plant were collected and stored separately in F.A.A. (formalin-acetic acid-ethyl alcohol) for later study.

The 2,4-D was applied at the following rates: 36.6, 18.3, 9.1, 4.6, 2.3, 1.1, 0.6, 0.3, 0.15, 0.075, 0.037, 0.018, and 0.009 pounds per acre. This was done by dissolving the pure 2,4-D in carbowax 1500 in the ratio of 1 to 10, adding a wetting agent (Triton 100X), dispersing in water, and spraying the resulting mixture on the soil. After drying, the soil was thoroughly mixed as outlined above.

The DDT and Colorado 9 were applied at a rate equivalent to 103 pounds per acre. Both compounds were first dissolved in 10 times their weight of xylene, dispersed in water through the aid of a wetting agent (Triton 100X), and sprayed on the soil.

RESULTS

EFFECT OF 2,4-D ON DEVELOPMENT OF BACTERIAL ROOT NODULES AND OTHER PLANT CHARACTERS

In these tests concentrations of 2,4-D as low as 0.009 pound per acre, when mixed with the soil, depressed the formation of bacterial root nodules. In the use of 2,4-D as a weed killer, the concentrations ordinarily used are 1.3 to 3.0 pounds of the pure chemical per acre (1 to 1½ gallons of spray per square rod at 1,000 to 1,500 p.p.m.). Bean plants 6 inches tall, sprayed with 2,4-D at concentrations of 0.009 to 1.2 pounds per acre formed no root nodules at concentrations greater than 0.075 pound per acre. This is the equivalent of applying a spray with a concentration of 38 ppm at a rate of 1½ gallons per square rod.

At concentrations above 9.1 pounds per acre, applied to the soil, the seeds failed to germinate and the cotyledons became swollen and malformed. At concentrations between 0.075 and 9.1 pounds per

TABLE 1.—*Some effects of 2,4-dichlorophenoxy acetic acid on common beans when grown in treated soil.*

Amt. of 2,4-D, lbs. per acre	Average Number of nodules per plant	General plant reactions
36.6	None	Seed failed to grow, cotyledons swollen on one end
18.3	None	Same as above
9.1	None	Same as above
4.6	None	Seed germinated, plant dwarfed, cotyledon leaves malformed with thickened veins
2.3	None	Plants dwarfed and cotyledon leaves malformed, secondary root formation stimulated
1.1	None	Cotyledon leaves with thickened veins, secondary root formation stimulated
0.6	None	Plants 6 inches tall, secondary root stimulation, stem bases swollen, first pair true leaves triangular in shape
0.15	None	Same as above
0.075	None	Plants 11 inches tall, no secondary root stimulation, leaves appear normal
0.037	1.0	Same as above
0.018	2.4	Same as above
0.009	5.3	Same as above
Check	24.03	Same as above

acre there were several kinds of characteristic disturbances such as wedge-shaped cotyledon leaves, dwarfed, swollen, and split stems, and thickened vascular structures. Nodule formation was completely inhibited. Between 0.009 and 0.037 pound per acre, plants attained their normal growth but nodule formation was depressed. All data are summarized in Table 1.

Where 2,4-D was sprayed on plants six inches tall at the rate of 0.15 to 1.2 pounds per acre, the plants were killed. At rates between 0.009 and 0.075 pound per acre, there were typical 2,4-D symptoms of leaf and stem curling, stem splitting, and lateral root stimulation. The average number of nodules per plant appeared similar to the checks, but microscopic examination showed significant changes. These changes included disintegration of some of the bacteria and host tissue and changes in the bacterial gram-stain reaction. General plant reactions are summarized in Table 2. Details of the changes in the bacteria will be reported in a subsequent paper.

TABLE 2.—*Some effects of 2,4-D when sprayed on common bean plants.**

Amt. 2,4-D, lbs. per acre	Average number of nodules per plant	General plant reaction
1.2	None	Plants killed
0.6	None	Plants killed
0.3	None	Plants killed
0.15	None	Plants killed
0.075	21.0	Leaves and stems show curling, stems split
0.037	9.5	Leaves and stems show curling, stems split and some lateral root stimulation
0.018	33.2	Slight stem and leaf curling, stem splitting
0.009	28.2	Stem splitting, slight stem and leaf curling
Check	24.03	Plants normal

*Plants 6 inches tall when sprayed.

EFFECT OF DDT AND COLORADO 9 ON NODULE FORMATION

For each treatment in this experiment, five pots each containing five plants were used. The chemicals were applied as described previously. A variance study was made of the number of nodules per plant produced by each of the three treatments, DDT, Colorado 9, and water. Since a highly significant "F" value was obtained, the "t" test was used for the minimum significant difference between the means (Table 3).

These data show that Colorado 9 and water differ significantly from DDT but not from each other. The mean number of nodules per plant for Colorado 9 was 21.16 and for water 22.72. The difference in these means was 1.56, which was not significant at the 5% level. The mean number of nodules per plant for DDT was 9.08. The difference between this mean and Colorado 9 was 12.08 and between this and water 13.64. These differences were highly significant at the 5% level. In other words, DDT at a rate of application of 103 pounds per acre applied to soil significantly depressed the number of nodules per plant, whereas Colorado 9 at the same rate did not.

TABLE 3.—*Analysis of variance of the number of nodules per plant on common beans grown in soil treated with DDT and Colorado 9.*

Variability due to	D/F	Sum of squares	Mean square (variance)	F value	Required F	
					0.05	0.01
Treatments	2	2,786.75	1,393.97	13.25	3.13	4.91
Within treatments (error)	72	7,571.24	105.16	—	—	—
Total	74	10,357.99				

Comparisons of Treatment Means by the "t" Test

Treatment	DDT	Colorado 9	Water	Differences between means required for significance	
				0.05	0.01
Mean number of nodules per plant	9.08	21.16	22.72	5.78	7.67

DISCUSSION AND SUMMARY

The lowest concentration at which 2,4-D prevented nodulation of common beans in this study was equivalent to an application of 0.075 pound per acre when the chemical was mixed in the soil before planting. Even at concentrations as low as 0.009 pound per acre, nodulation was depressed. These amounts are only from 0.3 to 5.8% of the amounts ordinarily employed when 2,4-D is used as a weed killer (1.3 to 3.0 pounds per acre). When 2,4-D was applied as a spray directly on rapidly growing beans 6 inches tall, at rates between 0.15 to 1.2 pounds per acre, the plants were killed. At rates from 0.009 to 0.075 pound per acre, tops showed typical 2,4-D symptoms, and the average number of nodules formed were but slightly different than the checks. However, microscopic examination of the nodules (treated plants) showed bacterial and host tissue disintegration and changes in the bacterial gram-stain reaction. Even at the lowest concentrations the tops showed characteristic 2,4-D stimulation.

Results of this study agree with the recent work of Appleman and Sears on the depressing effect of DDT on bacterial root nodules of legumes. It is also shown that 2,4-D has a similar effect but at much lower concentrations.

This study also emphasized that Colorado 9, an insecticide similar to DDT, did not depress bacterial root nodulation of common beans even at relatively high concentrations.

Controlling Field Bindweed by Grazing With Sheep[1]

L. M. Stahler and Arne E. Carlson[2]

EFFECTIVE tillage practices or combinations of tillage and cropping practices for the control of field bindweed, *Convolvulus arvensis* L., have been developed during the past 10 years. Many large-scale, statewide bindweed control programs now under way are based largely upon tillage and selective cropping. Long periods of intensive cultivation are necessary to reduce the reserve food storage of the bindweed root system and lower the vigor of the plant to the point where crops can successfully compete with it. This is the chief disadvantage of the method.

An alternative practice is the use of chemical weed killers, particularly sodium chlorate. Although these herbicides are effective and widely used, their cost is prohibitive on large areas, they often make the soil unproductive and their application often is unpleasant or dangerous.

The destruction of bindweed by grazing is nearly self-supporting and is not injurious to soil. It has long been known that sheep graze bindweed readily and many farmers have tried to kill the weed by heavy pasturing. This is difficult because bindweed has a low-carrying capacity in pure stands, and it is impossible to maintain sheep in good condition while the bindweed is being closely grazed. Bindweed is difficult to kill by grazing where it is growing in a bluegrass pasture because the denser growing grass partly protects the weeds by preventing the very close grazing of the leaves and stems which is necessary to kill the plants.

Investigations were started in 1938 at the Lamberton, Minn., Bindweed Experiment Station to determine the feasibility of controlling bindweed by grazing sheep on mixtures of bindweed and plants other than bluegrass.

MATERIAL AND METHODS

Fall-sown rye and wheat were chosen to accompany bindweed for spring grazing because these crops make rapid fall and early spring growth, furnish abundant spring pasturage, and continue growth until the latter part of June if not grazed too closely. The rye and wheat were not grazed in the fall. Unlike bluegrass, drilled stands of rye and wheat are not dense enough to protect the bindweed plants from selective grazing by sheep.

Sudan grass was used for summer pasture because it grows rapidly in midsummer after the rye and wheat pastures are exhausted. Sudan grass germinates and develops under conditions of low soil moisture, withstands grazing well, and is palatable to sheep. No prussic acid poisoning occurred on the Sudan grass grazed in these investigations.

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[1]Contribution from the Lamberton, Minn., Station in cooperation between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture; the College of Agriculture, University of Minnesota; and the Minnesota State Department of Agriculture. Received for publication August 1, 1946.

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The perennial pasture mixtures used in this experiment were alfalfa and bromegrass and alfalfa and reed canarygrass. These are the pasture mixtures recommended for the Lamberton area.

The first experiment, started in September 1938, employed duplicated plots 1/3 acre in size. In a second test begun in September 1939, the plots were increased in size to 4/5 acre but were not replicated. A third experiment, undertaken in 1941, utilized small plots 1/20 acre in size. When these experiments were started, all plot areas were heavily and uniformly infested with bindweed.

All plots were fenced with sheep netting during grazing periods, but the fences were removed at intervals to permit cultivation of the grazing plots and check plots as a unit.

A flock of 50 western crossbred ewes and their lambs were used for grazing each season. The ewes were dry-fed in the yard during the winter and early spring. Pasturing began as soon as plant growth was sufficient and was carefully controlled thereafter to avoid overgrazing. At the end of the season grazing was continued until all available green material was consumed before the plots were plowed. A good permanent bluegrass pasture was available for a reserve pasture when the experimental plots were not being grazed.

Yields of grazed forage were determined as clipped, dry material on a 15% moisture basis. Standard, steel, meter-square pasture cages were used to protect sample areas while plots were being grazed. Three such cages were used on each plot and square yard samples were taken on the area enclosed by each cage on each sampling date. The samples were taken at the beginning of each grazing period. Clipped forage yields from the permanent pasture were obtained each season as a measure of pasture production in the Lamberton area. Total nitrogen of the clipped forage was determined by the Kjeldahl method and expressed as the percentage of dry weight of the sample.

Bindweed counts were determined by the average of six or more square-yard quadrates taken at random over each plot in each treatment.

EXPERIMENTAL PROCEDURE AND DATA

The area used for the experiment started in 1938 was plowed on July 20, after harvesting a crop of winter rye. The plots to be sown to wheat or rye were tilled with a duck-foot field cultivator at 2-week intervals, until seeding time on September 15. Plots of pasture mixtures were sown on August 15, after a heavy rain. Excellent stands of all crops were obtained.

It became apparent early in the experiment that the sheep were very selective in their grazing habits. In early spring the animals grazed bindweed or rye without discrimination, but later, as the rye became less succulent, the sheep consumed all bindweed plants before grazing the rye heavily. When turned into wheat plots, the sheep always consumed the bindweed and the volunteer rye before grazing the wheat. In the bromegrass-alfalfa mixture, the alfalfa and bindweed were consumed before the bromegrass was eaten. This selective grazing apparently did not change the relative proportions of bromegrass-alfalfa during the period covered by the investigation. In the reed canarygrass-alfalfa mixture, the alfalfa was almost eliminated by 3 years of preferential grazing. Bindweed was grazed more readily than was reed canarygrass, but the coarse growth and dense stand of the partly grazed grass protected the bindweed vines and leaves from such close grazing as occurred in the rye and wheat plots.

During 1939, the bindweed grew rapidly after each successive grazing, and the vines were allowed to reach a length of 5 inches before the sheep were turned in again. When grazed, the bindweed plants produced numerous fine short stems with elongated narrow leaves

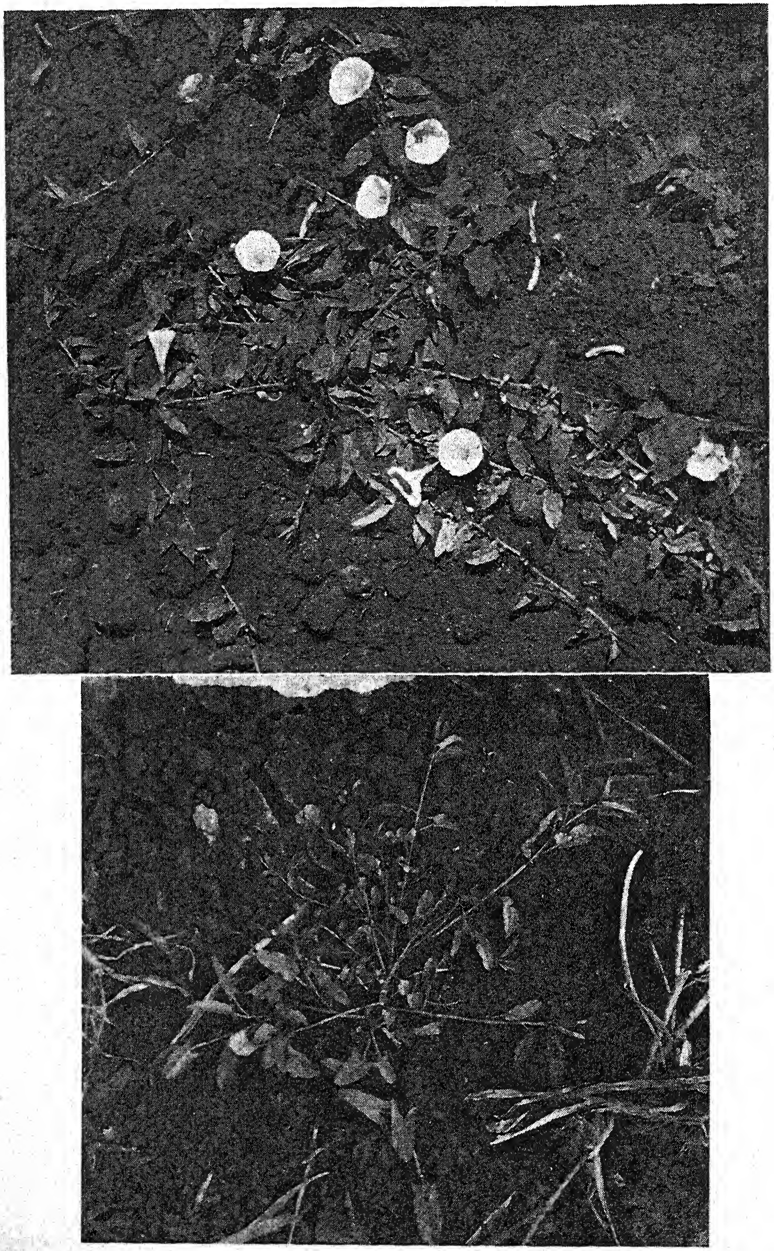

FIG. 1—*Above*, individual bindweed plant, one fourth natural size, June 20, 1938. *Below*, same plant, one half natural size, June 20, 1939, after a period of grazing by sheep.

instead of the normal type of growth consisting of three to five heavy stems with large spade-shaped leaves. The grazed plants, furthermore, failed to develop flowers (Fig. 1).

The plots were plowed July 1, 1939, after the rye and wheat had practically ceased growth. The ground was cultivated at 2-week intervals until September 15, when the plots were again sown to wheat or rye (Table 1).

Bindweed sprouts emerged in both the wheat and rye plots by September 25, but the pasturing had evidently weakened the weed because growth was much reduced during the fall.

In 1940, the plots were again grazed as in the previous season. By June 30, about 85% of the bindweed plants in the wheat and rye plots had been eliminated, whereas the number in the perennial pasture mixtures was greater than at the beginning of the experiment (Table 1).

By this time it was clear that the sheep had been so efficient in eliminating the bindweed that summer cultivation of the wheat and rye pasture plots was abandoned. Instead, the plots were plowed June 28 and seeded to Sudan grass on July 1. The Sudan grass was pastured periodically until September 10, when the plots were replowed and seeded to wheat or rye.

Sudan grass pasture proved to be an adequate substitute for summer cultivation. Although the sheep grazed the Sudan grass readily, they showed a slight preference for bindweed and only a trace of the weed appeared in the fall-sown grain. After two short periods of grazing in spring and early summer of 1941, the wheat or rye plots were left undisturbed until about August 10. No bindweed having appeared by that time, eradication was considered complete.

On the ungrazed (check) plots (treatments 5 and 6, Table 1), the bindweed increased from 1.2 to 12 plants per square yard in the rye plots and from 1.5 to 9 plants per square yard in the wheat plots. The check plots were separated from the grazed plots only by the fence, and they received the same cultural and cropping treatment except that they were not pastured but were harvested for grain and cultivated until fall seeding each year. In contrast to the grazed plots the bindweed plants on the check plots were vigorous and produced flowers and some seed each season.

Continuous grazing of the perennial pasture plots for three seasons did not reduce the original stand of bindweed (Table 1). The stand of bindweed increased markedly on in the plots of the ungrazed pasture mixtures cut for hay each season (treatments 7 and 8).

By September 1944, bindweed had spread 4 to 8 feet into the wheat and rye plots wherever they adjoined the plots used for hay production.

In the second group of ploto started in September 1939, only three treatments were used, wheat being discontinued because of the risk of winter killing in the Lamberton area. Treatments, yields, and other data are given in Table 2. One plot was planted to soybeans in June 1939 and rye seeded in the soybean stubble on September 15. Plots for treatments 2 and 3 were seeded with the pasture mixture on

TABLE 1.—*Treatment and bindweed survival on plots sown to winter rye, winter wheat, or pasture mixtures in 1938 and grazed with sheep, Lamberton, Minn.**

Treatment No.	Year			Number surviving bindweed plants per sq. yd. in July		
	1939	1940	1941	1939	1940	1941
1	Rye seeded Sept. 15, 1938, grazed May and June, cultivated to Sept. 15 when rye was again seeded	Grazed May and June, Sudan grass seeded July 1, grazed to Sept. 10 when seeded to rye	Grazed May and June	1.2	0.2	0
2	Wheat seeded Sept. 15, 1938, handled as above, wheat seeded again Sept. 15	Handled, as above, except wheat seeded Sept. 15	Grazed May and June	1.5	0.6	0
3	Alfalfa-bromegrass mixture seeded Aug. 15, 1938, grazed May 20 to Sept. 1	Grazed May 1 to Sept. 30	Grazed May and June	2.4	11.0	9
4	Alfalfa-reed canarygrass mixture seeded Aug. 15, 1938, grazed May 20 to Sept. 1	Grazed May 1 to Sept. 30	Grazed May and June	8.0	13.3	11
5	Handled as No. 1, except no grazing, rye harvested for grain	Rye harvested for grain	Rye harvested for grain	1.2	4.3	12
6	Handled as No. 2, except no grazing; wheat harvested for grain	Wheat harvested for grain	Winter wheat harvested for grain	1.5	4.0	9
7	Handled as No. 3, except no grazing; cut for hay	Cut for hay	Cut for hay	2.4	6.4	9
8	Handled as No. 4, except no grazing; cut for hay	Cut for hay	Cut for hay	8.0	8.2	12

*Plots 1/8 acre, duplicated.

April 20, 1939, with oats as a companion crop. No check plots were used.

The data in Table 2, and also those from the earlier experiment, indicate that the grazing of Sudan grass is a highly effective method of reducing the bindweed population. It appears to be superior to clean cultivation.

In general, 1½ to 2 seasons of intensive cultivation entailing 15 to 20 operations have been required to eliminate bindweed at Lamberton, Minn., wholly by tillage methods.

Grazing alternate crops of rye and Sudan grass completely eliminated bindweed in 1½ seasons. During the same time grazing of either of the perennial pasture mixtures reduced the bindweed population approximately 75%. Grazing was repeated on the alfalfa-bromegrass plot in 1943 and 1944. In September, 1944, after 5 years of grazing, the bindweed population on this plot still averaged 0.5 plant per square yard.

The plot planted to the reed canarygrass-alfalfa mixture was not pastured after 1942 but was cut for hay twice each season in 1943 and 1944. By September 1944, the canarygrass had eliminated all but a trace of the alfalfa and no bindweed could be found on the entire plot area.

In order to check the common belief that sheep are not effective in eliminating bindweed in pure stands, a third experiment was started in the fall of 1941 (Table 3). In one plot rye and Sudan grass were sown alternately as in the previous investigations, while the other plot received no treatment other than forced heavy grazing. Annual weeds that emerged on this plot each spring and summer were grazed off with the bindweed. At no time during the investigation were bindweed stems permitted to reach a length of more than 4 inches. The sheep showed a definite preference for the rye-bindweed or Sudan grass-bindweed combinations and when given a choice of grazing ignored the pure bindweed plot; yet in the cropped plots, they grazed bindweed plants in preference to either rye or Sudan grass. Such paradoxical behavior on the part of sheep is explained by the fact that bindweed growing with rye or Sudan grass is partly shaded and therefore more succulent than that growing alone and exposed to full sunlight. Bindweed shaded by rye or Sudan grass grows upright and is easily grazed, whereas the exposed plants grow prostrate and grazing is hindered by proximity to the soil.

Two seasons of grazing the plots sown to rye and Sudan grass completely eliminated the bindweed, whereas in the pure bindweed grazing had reduced the stand only 53% by July 1944.

No record was kept of the sheep-days of grazing furnished by the various crops or crop mixtures used in this investigation. Yields of clipped pasture herbage and crude protein content of the herbage produced on plots in 1939 and 1940 are given in Table 4. The yield and percentage crude protein from a good bluegrass pasture adjacent to the experimental plots also are shown. The data in Table 4 indicate that all of the crops grown produced satisfactory yields of herbage of high protein content.

TABLE 2.—*Treatment, yield of forage, and bindweed survival on plots sown to winter rye and sudan grass or to pasture mixtures in 1939 and grazed with sheep, Lamberton, Minn.**

Treatment No.	Year		Yield of clipped forage, dry weight in tons per acre			Number surviving bindweed plants per sq. yd. in July			
	1940	1941 and 1942	1940	1941	1942	1939	1940	1941	1942
1	Rye seeded Sept. 15, 1939, grazed May and June, plowed and seeded to Sudan grass July 1, grazed to Sept. 10, plowed, rye seeded Sept. 15	Handled as in 1940	Rye 2.8 Sudan 1.6	1.1 0.9	1.3 1.5	6.5 —	2.0 —	0.0 —	0.0 —
2	Alfalfa-brome mixture seeded Apr. 20, 1939, grazed May to Sept. 1940	Handled as in 1940	3.0	2.8	2.9	6.5	4.0	2.2	1.5
3	Alfalfa-canarygrass mixture seeded Apr. 20, 1939, grazed May to Sept. 1940	Handled as in 1940	3.4	2.9	3.1	6.5	3.0	2.0	1.2

*Plots 4/5 acre, not replicated.

TABLE 3.—*Treatment and bindweed survival on plots seeded in 1941 and grazed with sheep, Lamberton, Minn.**

Treat-ment No.	Year: 1942	Year: 1943 and 1944	Plot No.	Number surviving bindweed plants per sq. yard in July: 1941	1942	1943	1944
1	Rye seeded Sept. 15, 1941, grazed May and June, plowed and seeded to Sudan grass June 20, grazed to Sept. 15, 1942, seeded to rye	As 1942	1	12.0	6.0	Trace	0.0
			2	9.0	8.5	0.0	0.0
			3	13.5	5.0	Trace	0.0
			4	9.0	6.0	0.0	0.0
2	Undisturbed check plot, grazed as above but not seeded	As 1942	5	18.0	21.0	12.5	8.5

*Plots 1/20 acre, grazed as a single unit.

TABLE 4.—*Yields of clipped pasture herbage on bluegrass, rye-sudan, wheat-sudan, and two perennial pasture mixtures used for sheep grazing in bindweed control at Lamberton, Minn.; also percentage of crude protein of the herbage.*

Grazing crop	Yields of clipped herbage, air-dry basis, in tons per acre: 1939	1940	Crude protein in % of dry weight, 1939 and 1940: Range	Average
Bluegrass (old stand)	1.945	1.996	16.88 to 27.08	20.5
Rye	1.285	0.756	25.5 to 29.0	27.1
Sudan grass	——	1.452	21.0 to 26.0	23.5
Total*	——	2.208		
Wheat	0.838	0.814	24.0 to 32.0	28.0
Sudan grass	——	1.232	21.0 to 26.0	23.5
Total*	——	2.046		
Alfalfa-brome	2.315	3.686	22.0 to 27.0	24.5
Alfalfa-canarygrass	2.856	3.197	21.0 to 29.0	25.0

*Total herbage produced by the two consecutive crops in one year.

SUMMARY

1. Experiments were conducted at Lamberton, Minn., from 1939 to 1944 to determine the effectiveness of grazing sheep in controlling bindweed on infested land sown to several crops.

2. A combination of fall-sown wheat and rye grazed in May and June, followed by Sudan grass grazed in July and August, consistently eliminated bindweed in two seasons.

3. The grazing of perennial pasture mixtures consisting of alfalfa and bromegrass or alfalfa and reed canarygrass did not eliminate bindweed in any of three experiments.

4. The bindweed was not eradicated in ungrazed plots of rye and wheat harvested for grain, and plots of alfalfa-bromegrass and alfalfa-reed canarygrass mixtures cut for hay.

5. The grazing of pure bindweed reduced the stand somewhat, but this practice was much less effective than was the grazing of infested land on which crops were being grown.

6. Sheep grazed the bindweed in preference to wheat, rye, or Sudan grass. Rye was more palatable than was wheat. They grazed alfalfa, bromegrass, or bindweed without discrimination but preferred these to reed canarygrass. Bindweed growing with wheat, Sudan grass, or rye is grazed in preference to that grown alone in full sunlight.

7. Yields of clipped forage of the crops and crop mixtures used in this investigation were higher than yields from adjacent well-established bluegrass pasture. The crude protein content was high in all of the clipped herbage.

A Method for Determining the Use and Limitations of Rotation and Conservation Practices in the Control of Soil Erosion in Iowa[1]

G. M. BROWNING, C. L. PARISH, AND JOHN GLASS[2]

SINCE 1929, investigations have been in progress on soil and water conservation at the soil conservation experimental farms throughout the United States. These investigations have shown that a combination of factors must be considered in developing a comprehensive plan on any one farm if soil and water losses are to be kept at a desirable minimum. Research to date has shown that the main factors influencing runoff and erosion are the following: type of soil; type and amount of vegetation; length and steepness of slope; amount, intensity, and distribution of rainfall; and contouring, terracing, strip cropping, and other conservation practices. Three of these experimental farms are located on soils that occur extensively in Iowa. Results obtained on the Fayette soil at La Crosse, Wis., are applicable to the Fayette soils of eastern and northeastern Iowa. Studies at Bethany, Mo., on the Shelby soils are applicable to similar soils in southern Iowa, while the Marshall and associated soils of western and southwestern Iowa are represented by the farm at Clarinda, Iowa.

Most of the data from these studies were obtained on small plots with all factors constant except the one on which information was desired. The problem then is to put the information for each factor or any combination of factors together so that it can be used as a guide in developing land use recommendations on individual farms. That is, what are the cropping and soil management practices and conservation measures needed to reduce soil and water losses on a given field to the place where productivity will be maintained over a period of time? In order to achieve these objectives, gully formation must be prevented and loss of fertility by erosion, leaching, and crop removal should not exceed that which is being replaced or built up from the lower soil layers by the management practice that is being followed.

Considerable work (2, 4, 5, 7)[3] has been done to make available research information from these experimental farms to give aid to farm planners and others in developing land use recommendations.[4] However, the use of this information has been somewhat limited, probably because no attempt has been made to summarize the data and determine if generalizations could be made which would be applicable for soil types other than those on which the experiments were conducted. It is the purpose of this paper, therefore, to bring together detailed, specific information on the Marshall, Shelby, and Fayette

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[2]Soil Conservationists, Divisions of Research and Operations.

[3]Figures in parenthesis refer to "Literature Cited", p. 73.

[4]Also unpublished graphs by George M. Browning on the use of rotations and conservation practices.

soils and develop from these data certain principles that may possibly be used in combination with all other available data in preparing recommendations on other soil types in Iowa on which detailed, specific data are not available.

METHOD FOR DEVELOPING SLOPE LENGTH LIMITS FOR DIFFERENT PERCENTAGE SLOPES AND CONSERVATION PRACTICES

The formulas developed by Zingg (7) and applied by Smith (5) were found applicable to data obtained on the Marshall soils at the Clarinda, Iowa, experimental farm. The formula, which Zingg developed with the basic data obtained during the period 1933–42 from a 72.6 foot plot of moderately eroded Marshall silt loam on a 9% slope cropped to a corn-oats-meadow rotation with all crops surface planted up and down hill, is as follows:

$$L=\left(\frac{A_1}{PC}\right)^{5/3} S^{-7/3} \quad \text{where}$$

A, Average annual soil loss = 10 tons per acre

S, Land slope = 9 %

L, Length of slope = 72.6 feet. Length of slope in this paper is defined as the distance which water will travel at right angles to a contour line until it reaches a defined water channel which is or should be protected.

C, Constant which expresses the effect of weather, soil, crop rotation, degree of erosion or soil treatment on soil losses. This value = 0.035 and was obtained by substituting the above values of S, L, and A in the formula $C=\frac{A}{S^{7/5}L^{3/5}}$.

A_1, Maximum average annual permissible soil loss without decreasing productivity = 5 tons per acre. This value will vary with soil type since a given erosion loss is more serious on soil with a clay-pan or heavy infertile subsoil than on loessial soils of uniform texture throughout the profile. Estimated permissible soil losses for other soils in Iowa are shown in Table 3.

P, Effect of a conservation practice expressed as the ratio of the soil loss with a given practice to that of up and down hill cultivation. Average values for "P" were up and down hill cultivation, 1.0; contour cultivation, plowed and surface planted, 0.5; contour listed, 0.25; and contour strip cropping, surface planted, 0.25.

By using the formula $L=\left(\frac{A_1}{PC}\right)^{5/3} S^{-7/3}$ and substituting the value of 5 tons for A_1, 0.035 for C, 1.0 for P, and 9 for S, the calculated

by substitution in the equation $\left(\frac{1}{1.25}\right)^{5/3} = .69$. This factor is shown in Table 3, column 3. When any value in Table 1 is multiplied by that factor, the result is the slope length for Haig soil that will produce an average annual loss of about 5 tons per acre for that particular percentage slope and conservation practice. Adjustment factors for other

TABLE 4.—*Soil losses from plots 72.6 feet long on a 9% slope and estimates for various cropping systems on Marshall silt loam.*

Crop sequence	Average soil loss, tons per acre, per year
Continuous corn	40*
Corn after 1 year of meadow	20†
Corn after 2 years of meadow	16
Corn after 3 years of meadow	14
Corn after 4 years of meadow	13
Corn after 5 years of meadow	12
Corn after corn after 1 year of meadow	26
Corn after corn after 2 years of meadow	24
Corn after corn after 3 years of meadow	23
Corn after corn after 4 years of meadow	22
Corn after corn after 5 years of meadow	21

Oats after corn—one-half the loss of the corn immediately preceding the oats
Wheat after corn—one-fourth of the loss of the corn immediately preceding
Soybeans—approximately the same loss as corn

*Represents measured values, Clarinda, Iowa. All other figures estimated.
†Meadow soil loss negligible and not considered in calculating the average soil loss for the rotation.

TABLE 5.—*Rotation slope length factors.*

Rotations*	Annual soil loss, tons per acre	Rotation slope length adjustment factor
Continuous corn	40.0†	0.10
C-C-O- (scl)	19.6	0.33
C-O- (scl)	15.0	0.51
C-C-O-M	14.8	0.52
C-O-M-C-O- (scl)	12.0	0.73
C-C-O-M-M	10.4	0.93
C-O-M	10.0†	1.00
C-C-O-M-M-M	8.1	1.41
C-O-M-M	6.0	2.35
C-O-M-M-M	4.2	4.24
C-O-M-M-M-M	3.25	6.45
C-O-M-M-M-M-M	2.6	9.42

*C = corn; O = oats; M = meadow.
†Data available for continuous corn and a rotation of corn, oats, and meadow. All other values estimated from figures in Table 4.

Recommendations:

A. When the slope length in the field is less than or equal to the slope length limit, the rotation and practice should give adequate control.
B. If the slope length in the field exceeds the limitation, a more intensive conservation practice or a less intensive rotation, or both, is recommended. Conversion to permanent vegetation is recommended when the field slope length exceeds the limitations of any practical combination of rotations and practices.
C. On terraced fields, if the limitation is less than the horizontal terrace spacing, the rotation is too intensive and may result in excessive erosion between terraces.

TABLE 3.—*Estimated comparative erodibility and permissible soil losses for different soil types and calculated slope length adjustment factors.*

Soil group*	Soil type	Soil loss, tons per acre	Soil loss, slope length adjustment factor	Permissible soil loss, tons per acre	Permissible soil loss slope length adjustment factor	Soil factor
A	Marshall	40†	1.0	5	1.0	1.0
B	Sharpsburg	45	0.82	5	1.0	0.82
C	Clarion	45	0.82	4	0.69	0.57
E	Storden	45	0.82	3	0.43	0.35
G	Dodgeville (deep)	45	0.82	2	0.22	0.18
D	Fayette	50†	0.69	4	0.69	0.48
G	Rockton (deep)	50	0.69	2	0.22	0.15
B	Ida	55	0.59	6	1.35	0.80
E	Clinton	55	0.59	4	0.69	0.41
F	Shelby loam	55†	0.59	3	0.43	0.25
F	Weller	60	0.51	3	0.43	0.22
G	Malvern	60	0.51	2	0.22	0.11
G	Dubuque (shallow)	70	0.39	2	0.22	0.09

*It was estimated that these soil types are representative of groups of soils in erodibility characteristics, and that the other soils types can be grouped in Table 2 insofar as their probable soil losses under similar conditions and treatments are concerned. Texture of the soil is silt loam unless otherwise indicated.

†Represents actual measured values on 9% slope Marshall silt loam. Results on Fayette silt loam obtained on 16% slope and on 8% slope for the Shelby loams but adjusted to 9% slope, using slope soil loss relationship as discussed in paper.

and chemical information relating these soils to other soils, estimates were made of comparative soil losses of other important soil types in Iowa which are shown in Table 2. These values assume continuous corn as the crop and the same conditions as at the Clarinda experimental farm on the Marshall soils. These values are estimates and are subject to revision as actual information is obtained.

It can be shown that the value C in the formula varies as the ratio of the soil loss on Marshall to that of any other soil. By substituting this ratio for C, a slope length ratio or factor can be obtained for adjusting Table 1 to soils that erode at a different rate than Marshall. For example, soil loss from Marshall was 40 tons per acre, but it is estimated at 50 tons per acre from Haig (Table 3). Then $\frac{50}{40} = 1.25$ and

TABLE 1.—*Slope length limits for a corn-oats-meadow rotation, base table.*

Slope,	Length of slope, feet		
	No conservation practices	Contour surface plant	Strip crop or contour list
2	770	2,460	7,700
3	300	950	3,000
4	150	490	1,500
5	90	290	900
6	60	190	600
7	40	130	410
8	30	100	300
9	25	70	230
10	20	60	180
11	15	50	150
12	12	40	120
13	10	30	100
14	8	25	80
15–17	6	20	60
18–20	4	13	40

TABLE 2.—*Rotation-soil factor.*

Rotations*	Soil groups†						
	A	B	C	D	E	F	G
C-C-O-(scl)	0.3	0.3	0.2	0.15	0.1	0.08	0.06
C-O-(scl)	0.5	0.4	0.3	0.25	0.2	0.1	0.09
C-C-O-M	0.5	0.4	0.3	0.25	0.2	0.1	0.09
C-O-M-C-O- (scl)	0.7	0.6	0.4	0.35	0.3	0.2	0.1
C-C-O-M-M	0.9	0.8	0.5	0.45	0.4	0.2	0.2
C-O-M	1.0	0.8	0.6	0.5	0.4	0.3	0.2
C-C-O-M-M-M	1.4	1.2	0.8	0.7	0.6	0.4	0.3
C-O-M-M	2.4	1.9	1.3	1.1	1.0	0.6	0.4
C-O-M-M-M	4.2	3.5	2.4	2.0	1.7	1.1	0.8
C-O-M-M-M-M	6.5	5.3	3.7	3.1	2.6	1.6	1.2
C-O-M-M-M-M-M	9.4	7.7	5.4	4.5	3.9	2.4	1.7

*C = corn; O = oats; M = meadow.
†Soils grouped according to soil loss hazards as follows:
A, Castana‡, Judson, Marshall, Muscatine, Napier‡, Tama, Waukesha.
B, Downs, Ida‡, Mahaska‡, Monona‡, Sharpsburg.
C, Carrington loam and silt loam, Clarion loam and silt loam.
D, Bertrand, Clarion sandy loam, Dubuque (deep), Fayette, Givin‡, Haig, Jackson, Lansing, Racine, Shelby silt loam.
E, Clinton, Coggan‡, Pershing, Storden.
F, Bucknell‡, Burchard, Lindley, Seymour‡, Shelby, Steinauer, Weller.
G, Clarinda‡, Dodgeville (deep), Dodgeville (shallow), Dubuque (shallow), Gosport, Malvern‡, Rockton‡ (shallow), Sogn.
‡Tentative names, not correlated.

To use the tables:

1. In Table 1, select the per cent of slope and conservation practice to be used. Read the base slope length.
2. In Table 2 select the soil group and rotation to be used. Read rotation soil factor.
3. Multiply base slope length by rotation-soil factor.
4. Result is the limit of slope length on which this combination of rotation and practice should be used.

length of slope L is 25 feet. This is the "slope length" which should result in an average annual soil loss of about 5 tons per acre when using a corn-oats-meadow rotation, with cultivation up and down hill on a moderately eroded Marshall silt loam under the climatic and management conditions found on the Clarinda experimental farm. In Table 1, the calculated " slope lengths" are given for the different slope percentages which range from 2 to 20 .These calculated "slope lengths" are shown for the following practices: No conservation practices; contour surface plant, and strip crop or contour list. In calculating the "slope lengths" for "contour surface plant" practices, the value of 0.5 was used for P in the formula. To determine the "slope lengths" for "strip cropping or contour listing" practices, the value of 0.25 for P was used. The value for contour listed is based on data from the Clarinda soil conservation experimental farm and for contour surface planting and strip cropping on results obtained at the Bethany soil conservation experimental farm. In Table 1 the calculated "slope lengths" are given for different slope percentages, or gradients. In addition, these "slope lengths" are calculated for three different kinds of conservation practices. The following example illustrates how these calculations are made:

No conservation practices; slope is 8%.

$$L = \frac{A_1}{PC}^{5/3} S^{-7/3}$$

L = "slope length"
A_1 = 5 tons permissible (estimated) soil loss per acre
P = constant (no conservation practice) = 1.0
C = constant = 0.035
S = 8 %

$$\therefore L = \frac{5}{1.0 \times 0.035}^{5/3} (8)^{-7/3} = 30 \text{ feet}$$

Table 1 has limited application because it applies to only one soil, one crop rotation, and one rate of permissible soil loss. A series of tables could be developed for different rotations on the Marshall soil and for other soils with different rates of soil loss. However, a large number of tables would be required to cover the entire range of conditions. Since all values affecting soil losses, with the exception of length and per cent of slope, are included in C of the formulas, it is easier and more convenient to develop a series of factors for each of the following variables: (a) Comparative rate of soil loss for different soils, (b) permissible soil loss, and (c) different crop rotations, which can be used for arriving at the slope length limit for any specific condition.

ERODIBILITY AND PERMISSIBLE SOIL LOSS FACTORS

Soil loss data are available for the Marshall, Shelby, and Fayette soils (1, 3, 6). With these data as a guide and using other physical

soils listed in Table 3 have been calculated and are shown in column 3.

Estimated permissible soil losses are shown in Table 3, column 4. The adjustment factors for permissible soil loss (Table 3, column 5), were calculated in the same manner as the erodibility slope length adjustment factor.

Another value called the "soil factor" is shown in Table 3, column 6, and is obtained by multiplying the erodibility slope length adjustment factor by the permissible soil loss adjustment factor.

ROTATION SLOPE LENGTH FACTORS

The measured soil losses from continuous corn, rotation corn, rotation oats, and rotation clover as obtained on the Marshall soils at Clarinda are shown in Table 4. Data showing the effect of increasing number of years of meadow in the rotation on soil and water losses after the soil is plowed and planted to corn for 1 or more years are limited. Apparently this effect varies widely with soils, climatic conditions, and the type and quality of the meadow as shown by results on the Fayette silt loam at La Crosse, Wis., the Shelby silt loam at Bethany, Mo., and the Marshall silt loam at Clarinda, Iowa. For example, on the Marshall silt loam 1 year of meadow has reduced soil losses from the following corn crop by about 50% in comparison with continuous corn. Data on the Shelby silt loam and Fayette silt loam indicate that most of the residual effect of meadow on soil losses disappeared in about 2 or 3 years. However, on the Marshall silt loam at Clarinda soil losses from third year corn following 11 years of alfalfa and bluegrass were 42.5 and 22.5%, respectively, of that from first year corn following meadow in a rotation of corn, oats, and meadow. Using comparative physical and chemical data and field observations and data from other soil conservation experimental farms as they relate to soils on which detailed runoff and erosion data are available, estimates were made of soil losses that might be expected from other crops in the rotation. The soil losses for individual crops in the rotation were then combined to arrive at the average soil loss for different rotations (Table 5). The rotation slope length adjustment factor (Table 5, column 3), was calculated in the same manner as described previously for the erodibility and permissible soil loss adjustment factors. These rotation factors when multiplied by the soil factors (Table 3, column 6), give a series of single factors, referred to as rotation-soil factors, as shown in Table 2. Multiplying the rotation-soil factor by the base slope length gives the length of slope on which this combination of soil-rotation and conservation practice should be used. If the slope length in the field exceeds the limitations, a more intensive conservation practice or a less intensive rotation or both is recommended.

ADJUSTMENT FOR SEVERE EROSION AND SOIL TREATMENT

It has been assumed that under Iowa conditions the increased soil loss under severely eroded conditions would be in the same proportion on other soil types as on Marshall. On the control plots at Clarinda, Iowa, moderately eroded Marshall soil under continuous corn lost 40

tons per acre annually, whereas severely eroded Marshall lost 53 tons per acre. In general, soil treatments in the form of manure, lime and fertilizers, and green manure crops have reduced the soil losses on severely eroded sites to about the same magnitude as on moderately eroded sites, although this may vary materially for different soil types. If the farm plan provides for the use of soil treatments on severely eroded crop land, the same rotation-soil factor may be used on these sites as for moderate erosion. If treatment is not provided for, the rotation-soil factor for severely eroded areas will be 0.6 of that for moderately eroded areas. This factor is calculated in the same manner as the factors for soil types in Table 3, i.e., $\frac{53}{40} = 1.325$ and

$$\left(\frac{1}{1.325}\right)^{5/3} = 0.62.$$

Some of the trials at experimental farms have shown that lime, fertilization, and the addition of organic matter to moderately eroded soils may decrease the soil losses 10 to 30%. The amount of decrease varies with soil types and with the amount and kind of treatment. Further data are needed before the effects of treatment can be evaluated in terms of length and steepness of slope. The average reduction in soil loss due to soil treatments such as a good farmer might apply is about 20%. Following the same method of calculation as used above, this results in an adjustment factor of 1.4 that may be used for adjusting slope limits because of good soil treatment on moderately eroded soils. In other words, the rotation-soil factor in Table 2 may be multiplied by 1.4 if complete soil treatment is made by the addition of substantial amounts of lime, fertilizer, and manure or organic matter other than that provided in the rotation.

It should be recognized that specific soil and water loss data were available for only three soils and that estimates, based on physical and chemical properties of other soils as they are thought to relate to the soil on which detailed data are available, were used when necessary. Although the values may need to be changed as actual information becomes available, they do serve as a guide based on the best information available at present for determining the probable effectiveness and limitations of proposed erosion control practices or for comparing the probable effectiveness of alternate plans. The effect of the managerial ability of the farm operator, the variation in climatic conditions, or the level of fertility, all of which are factors which determine the measure required to conserve soil and water and maintain productivity, were not considered in preparing the table. This was due to the lack of information on these admittedly pertinent factors as they relate to soil and water losses.

SUMMARY

Investigations at soil conservation experimental farms throughout the United States have shown the effect between runoff and erosion

and of soil type; type and amount of vegetation; length and steepness of slope; amount, intensity, and distribution of rainfall; and contouring, terracing, strip cropping, and other conservation practices, on runoff and erosion. The results on the Fayette, Shelby, and Marshall soils as found on the La Crosse, Wis., Bethany, Mo., and Clarinda, Iowa, farms are representative of large areas of soil in Iowa.

Using specific data from these soils as a guide and from observation and physical and chemical properties available on related soils on which soil and water loss data are not available, a guide has been developed for all soil mapped in Iowa, showing the use and limitations of rotation and conservation practices in the control of soil erosion.

Even though estimates were used when necessary and may need revising when more specific data are obtained, it is believed that the results show the general trend and that they should be helpful in making better land use recommendations.

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Notes

HOW TO MAKE A STANDARD YIELD DIAGRAM

ONCE an agronomist has had experience with the standard agrobiologic yield diagram derived from the Mitscherlich-Baule theorem, he finds it an indispensable tool in interpreting the results of tests with fertilizers, in variety comparisons, and in other applications of quantitative agrobiology. More agronomists would probably use the yield diagram if they understood how to construct and use a working copy of the diagram without having to make laborious computations by the Mitscherlich-Baule yield equation. The following directions will enable one to do this without any calculations.

Take a 20 x 20 inch sheet of cross section paper ruled in inches and tenths of an inch. Number the vertical divisions (ordinates) from 0 to 20. These numbers will be 1 inch apart and will represent units of yield per acre. Divide the horizontal axis (abscissas) into 10 units. This will allow 2 inches per baule, so that 0.1 inch will represent 1/20 (0.05) baule. On the cross section paper that has been scaled in this manner, draw the curves for $A=10$ to $A=24$, inclusive, using the coordinates given in Table 1 (baules against units of yield). Connect the points smoothly with the aid of a French curve. The finished diagram will have the general appearance of Fig. 1, except that 1/10 inch divisions are not here shown. After the whole-number curves have been drawn the coordinates of the intermediate curves (16.5, 17.5, 18.5, etc.) may be located by making penciled points half way between the whole-number curves.

Suppose that a field test with potash has yielded the data shown in Table 2. The first step in diagraming this experiment is to reduce pounds of potash to equivalent baules. A baule of potash is 82 pounds, so there were 0, 1, 2, and 3 baules. The next step is to divide the observed yields by a factor that will bring them within the range of the diagram, which is scaled for a maximum of 20 yield units. A suitable factor for this case is 4, which reduces the observed yields in bushels to 12, 14, 15, and 15.5 yield units. The third step is to lay a sheet of transparent paper on the unoccupied space of the diagram below curve A = 10. On this paper trace a horizontal line coinciding with any horizontal line of the diagram, say line 2. Trace also a vertical line (on ordinate 4, for example) intersecting the horizontal line. Let horizontal line 2 temporarily represent yield-unit line 11. On the vertical line of the transparent paper make a pencil dot to represent the yield from the check plots (12 units). Two yield-units above this dot and 1 baule to the right make a dot to represent the 14 yield-units; one unit above that dot and 1 baule farther to the right make a third dot for the 15 units, and a fourth dot 1/2 yield-unit above that, and 1 baule still farther to the right, for the 15.5 yield-units.

The fourth step is to pick up the transparent paper and place its horizontal line on line 11 in the body of the diagram. A first position, as *A*, may not show a fit, nor yet when the paper is slided on line 11 to another position *B*, but eventually all 4 points fit snugly (position C) on curve A = 16, which becomes $A=64$ when multiplied by 4 to re-

TABLE 1.—*Coordinates for a standard agrobiologic yield diagram.*

Baules of growth factor	Values of A														
	10	11	12	13	14	15	16	17	18	19	20	21	22	13	24
	Units of Yield														
0.25	1.59	1.75	1.91	2.07	2.23	2.39	2.54	2.70	2.86	3.02	3.18	3.34	3.50	3.66	3.82
0.50	2.93	3.22	3.51	3.80	4.10	4.39	4.68	4.97	5.27	5.56	5.86	6.15	6.44	6.73	7.02
0.75	4.05	4.46	4.86	5.27	5.68	6.08	6.49	6.89	7.30	7.70	8.11	8.51	8.92	9.32	9.73
1.00	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00
1.20	5.65	6.22	6.78	7.34	7.90	8.47	9.03	9.60	10.16	10.73	11.29	11.85	12.42	12.98	13.55
1.40	6.21	6.83	7.45	8.08	8.70	9.32	9.94	10.56	11.18	11.80	12.42	13.05	13.67	14.29	14.91
1.60	6.70	7.37	8.04	8.71	9.38	10.05	10.72	11.39	12.06	12.73	13.40	14.07	14.74	15.41	16.08
1.80	7.14	7.85	8.57	9.28	9.98	10.68	11.40	12.11	12.82	13.54	14.25	14.96	15.68	16.39	17.10
2.00	7.50	8.25	9.00	9.75	10.50	11.25	12.00	12.75	13.50	14.25	15.08	15.75	16.50	17.25	18.00
2.20	7.82	8.60	9.38	10.17	10.95	11.73	12.51	13.30	14.08	14.86	15.64	16.43	17.21	18.00	18.78
2.40	8.10	8.92	9.73	10.54	11.35	12.16	12.97	13.78	14.59	15.40	16.21	17.01	17.83	18.64	19.45
2.60	8.35	9.18	10.02	10.85	11.69	12.52	13.36	14.19	15.03	15.86	16.70	17.53	18.37	19.21	20.05
2.80	8.56	9.42	10.28	11.13	11.99	12.84	13.70	14.56	15.42	16.30	17.15	17.99	18.84	19.69	—
3.00	8.75	9.62	10.50	11.37	12.25	13.12	14.00	14.87	15.75	16.62	17.51	18.38	19.25	20.12	—
3.20	8.91	9.80	10.69	11.58	12.47	13.37	14.26	15.15	16.04	16.93	17.82	18.72	19.61	—	—
3.40	9.05	9.55	10.86	11.76	12.67	13.57	14.48	15.38	16.29	17.20	18.10	19.01	19.91	—	—
3.60	9.17	10.09	11.01	11.93	12.84	13.76	14.68	15.60	16.51	17.43	18.33	19.27	20.19	—	—
3.80	9.28	10.21	11.14	12.07	12.99	13.92	14.85	15.78	16.71	17.63	18.56	19.49	—	—	—
4.00	9.37	10.31	11.25	12.19	13.12	14.06	15.00	15.94	16.87	17.81	18.75	19.68	—	—	—
4.50	9.56	10.51	11.47	12.42	13.38	14.34	15.29	16.25	17.20	18.16	19.11	20.07	—	—	—
5.00	9.68	10.65	11.62	12.59	13.56	14.53	15.50	16.46	17.43	18.40	19.37	—	—	—	—
6.00	9.84	10.83	11.81	12.80	13.78	14.77	15.75	16.73	17.72	18.70	19.69	—	—	—	—
7.00	9.92	10.91	11.90	12.89	13.89	14.88	15.88	16.87	17.86	18.85	19.84	—	—	—	—
8.00	9.96	10.96	11.95	12.95	13.94	14.94	15.94	16.93	17.93	18.92	19.92	—	—	—	—
9.00	9.98	10.98	11.98	12.97	13.97	14.97	15.97	16.97	17.96	18.96	19.96	—	—	—	—
10.00	9.99	10.99	11.99	12.99	13.99	14.99	15.99	16.99	17.99	18.99	19.99	—	—	—	—

TABLE 2.—*Preparation of data for plotting on the standard yield diagram.*

Plot series	K_2O used		Yields, bu. per acre	Yields × 1/4
	Lbs. per acre	Equivalent baules		
1	0	0	48	12.0
2	82	1	56	14.0
3	164	2	60	15.0
4	246	3	62	15.5

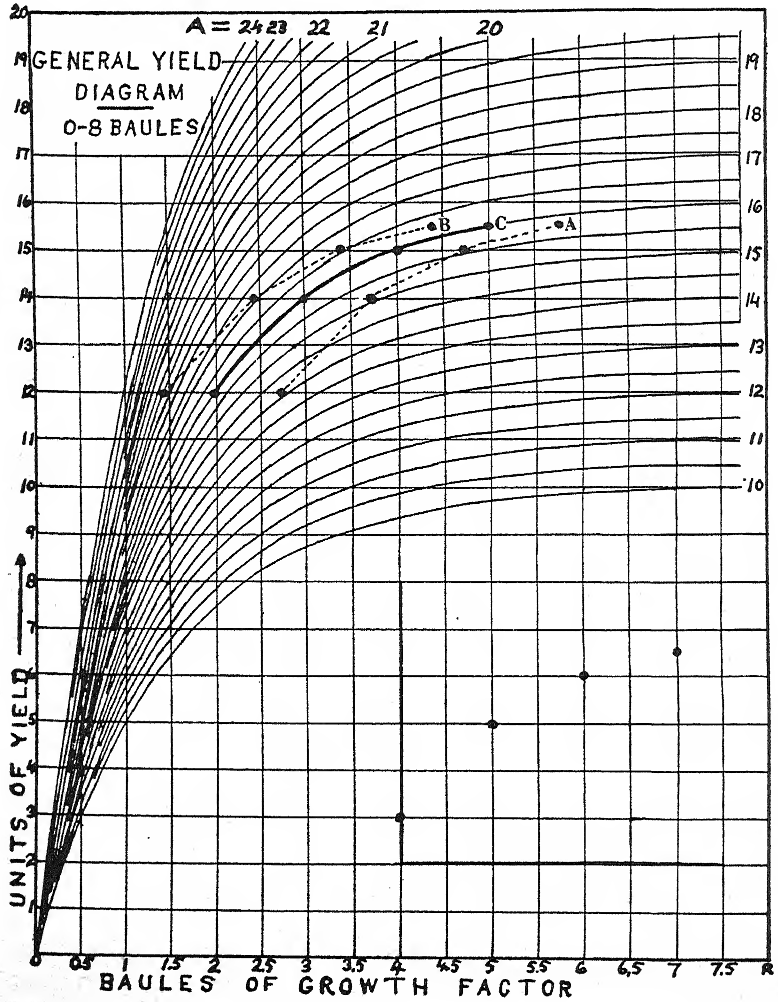

FIG. 1.—General agrobiologic yield diagram.

store the original relation. The agrobiologic characteristics of the field on which this test was made are thereby determined. The applicable Mitscherlich-Baule yield equation is $\log(64-y) = \log 64 - 0.301x$. The average K_2O content of the untreated soil was 2 baules (the point representing the yield of the check plots falls on ordinate 2). This soil is quite normal (absence of yield-depressing factors). The indicated maximum yield from simple potash fertilization is 64 bushels per acre, which is much less than the corn plant can yield. To obtain higher yields it will be necessary to investigate other factors. The perfect fit on curve $A = 16$ is a sign that the replication was adequate and that the operator made no major errors of manipulation.

The diagram of Fig. 1 is called the general yield diagram because it is scaled for baules up to 8, beyond which no benefit can be derived from any further quantity of fertilizer. However, field experimenters seldom use more than a total of 1 baule (223 pounds) of nitrogen and frequently use as little as 10, 20, 40, and 80 pounds per acre, equivalent to 0.044, 0.089, 0.178, and 0.356 baule. It is inconvienent to plot yields from such small fractions of a baule on the general diagram, especially in the region where the curves are crowded. Field testers should therefore provide themselves with two other standard yield diagrams, one for very small increments of fertilizer (0 to 2 baules) and the other for intermediate quantities (0 to 4 baules) on the 20 × 20 inch sheet. The horizontal axis of the first will show 1 baule per 10 inches, whereon 1/10 inch division will represent 0.01 baule (which by visual estimation may be read to 0.001). The other will have 1 baule per 5 inches, and 1/10 inch = 0.02 baule. On these special diagrams the curves are spread farther apart.

TABLE 3.—*Data for computing a standard agrobiologic yield diagram on any scale.*

Baules	% of A	Baules	% of A	Baules	% of A	Baules	% of A	Baules	% of A
0.1	6.70	1.0	50.00	1.9	73.21	2.8	85.64	3.7	92.31
0.2	12.94	1.1	53.35	2.0	75.00	2.9	86.60	3.8	92.82
0.3	18.77	1.2	56.47	2.1	76.67	3.0	87.50	3.9	93.30
0.4	24.21	1.3	59.39	2.2	78.24	3.1	88.34	4.0	93.75
0.5	29.29	1.4	62.11	2.3	79.69	3.2	89.12	5.0	96.88
0.6	34.02	1.5	64.64	2.4	81.05	3.3	89.85	6.0	98.44
0.7	38.44	1.6	67.01	2.5	82.32	3.4	90.53	7.0	99.22
0.8	42.57	1.7	69.22	2.6	83.51	3.5	91.16	8.0	99.61
0.9	46.41	1.8	71.28	2.7	84.61	3.6	91.75	9.0	99.80

Coordinates for these special diagrams may readily be computed (slide rule for simple multiplication) from Table 3, which shows the percentage of a maximum yield obtainable from a given number of baules of any growth factor. For example, suppose that the coordinates of $A = 25$ are being computed. Start at the head of the first column in Table 3 where it is given that 0.1 baule will produce 6.70% of any maximum crop. For curve $A = 25$, $0.067 \times 25 = 1.65$, which is the point where this curve will cross ordinate 0.1; $0.1294 \times 25 = 4.23$, the point where it will cross the ordinate 0.2, etc.—O. W. WILLCOX, *197 Union St,. Ridgewood, N. J.*

A METAL PLANT BAND[1]

THERE is a sizable industry in the manufacture and sale of paper bands and pots for starting seedlings that are later transplanted to larger pots or into the field or garden. A considerably bigger industry would be possible if more satisfactory containers were available. Bands help to contain the growing roots, and in transplanting, a fairly definite amount of soil is retained by the seedlings, resulting in less damage to the root system. Consequently, seedlings transplanted from bands are not set back in development so much as those transplanted from soil flats without the aid of bands.

Because of certain well-known disadvantages that paper and wooden bands have, in addition to a deleterious effect on plant growth[2], the writer tried to work out a practical plan for making bands from sheet metal. The original idea was improved upon by Gus Tornsjo (formerly mechanician in the machine shops at the University of Missouri), who made some dies and showed student laborers how to use the dies and the machines required to operate them. The students turned out about 8,000 of the bands, cutting strips out of 28-gauge galvanized sheet metal and shaping them into bands. These bands were approximately 2 inches square and 2½ inches deep, but later 3,000 of a smaller size (about 1½ inches square but the same depth) were produced. Some of the bands are shown in Fig. 1. Both sizes have now been used over a period of 11 years by the Genetics Group and members of other departments at the University of Missouri and have proved highly satisfactory.

No record has been kept of the number of times the bands have been used, but it may be conservatively estimated that on the average each band has been used six times per year. Thus, the bands have been used at least 60 times. Only in the last year or two have the bands shown much evidence of rust, and 80% or more of the bands are still in use. Actually, almost all of the bands no longer in use became unusable from abuse, being stepped on, run over by vehicles, lost, etc., rather than from deterioration.

At the time the metal bands were first used instead of paper bands, it was noted that the seedlings grown in the metal bands seemed to have better color and vigor. Recently tests were made comparing seedlings grown in the metal and paper bands. The paper bands tested were a light cardboard commercial type (not impregnated with paraffin or nutrients) and the metal bands were some of the best of the 11-year-old bands.

Comparisons between the paper and the metal bands were made using seed from a single ear of open-pollinated yellow field corn, Purdue No. 31 hybrid popcorn, and Stokesdale tomatoes. The bands (2-inch size) were put in standard greenhouse flats (14 x 20 inches), 70 bands to the flat. In the test using field corn, half of the bands in the flat were metal and half were paper; in the other tests whole flats were made up with only one type of band. The soil used was well pro-

[1]This work was carried out in cooperation with the Missouri Agricultural Experiment Station. Contribution from the Field Crops Department, Missouri Agricultural Experiment Station, Journal Series Paper No. 1005.

[2]JONES, L. H. Revealing study of plant bands. Horticulture, 23:316. 1945.

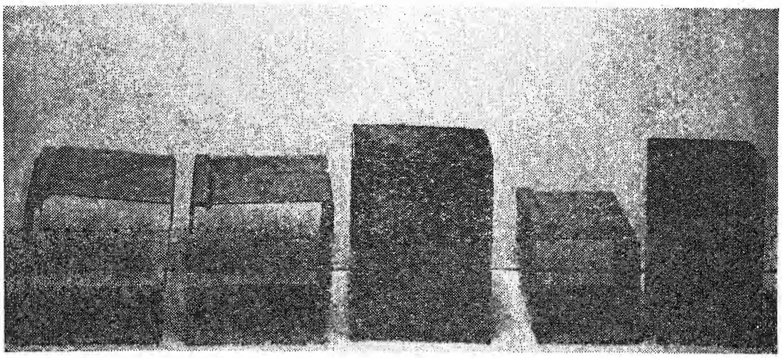

Fig. 1.—Three of the 2-inch-square galvanized iron bands (left) and two of the 11/2-inch-square bands (right). The band on the left is opened to show how the bands are crimped so they may be fastened to form a square. Other types of crimps could be used for the purpose. It also shows how the bands may be easily opened when the seedlings are transplanted.

vided with commercial fertilizer and humus. The flats were turned every few days to equalize the light.

Data on the weights of the seedlings are presented in Table 1. The plants were cut off at the surface of the soil and only the tops were weighed. Plants grown in the metal bands weighed considerably more than those grown in the paper bands, and it was regularly observed that with both tomatoes and corn the seedlings grown in the metal bands had a healthier, darker green color.

Table 1.—*Comparison of growth of corn and tomato seedlings in 2-inch square paper and metal bands.*

Bands	Seedlings at harvest				
	Age, days	Number	Green weights, grams		Relative weights, %
			Total	Average	
		Field Corn			
Paper	79	31	222	7.2	100
Metal	79	32	373	11.7	162
		Popcorn			
Paper	55	35	430	12.3	100
Metal	55	33	476	14.4	117
		Tomatoes			
Paper*	50	178	1,334	7.5	100
Metal*	50	178	2,035	11.4	152
None†	50	153	2,003	13.1	175

*Summary of five tests.
†Summary of four tests.

Whether the seedlings grown in the metal bands were or were not benefitted by iron, zinc, copper, or possibly other elements in the bands was not determined. Although the tomato seedlings grown in metal bands weighed somewhat less than the seedlings grown in open flats, this reduction might be accounted for by the fact that the root systems were more crowded in the bands or that the bands reduced the amount of soil available. If there was any beneficial effect of elements in the galvanized iron bands, that would be an advantage not obtainable in other types of sheet metal, such as aluminum, that could be used in the manufacture of bands. Bands from sheet aluminum would have a greater initial cost but would presumably last longer.

At least part of the deleterious effect of paper bands on growth can be overcome by impregnating them with nutrients, paraffin, or by the application of available nitrogen when the plants begin to show symptoms of nutritional deficiency. Even if there were no better growth of seedlings in the metal bands, they have other obvious advantages. The metal bands, being rigid, are easier to handle, and can be used over and over resulting in a considerable saving over a period of time. Another advantage, particularly important in experimental work, is that individual plants can be moved without injuring the others.

There is, however, one big disadvantage to the galvanized iron bands. Those described herein do not nest, a serious disadvantage if shipping costs and storage have to be considered. However, this is not an insuperable difficulty. One possible solution would be to make the bands in two parts which could be put together at their destination. Another possibility would be to develop a die or press that would produce bands slightly smaller at one end so they would nest. Still another would be to make bands similar to the ones shown in Fig. 1 except that the three bends changing the shape from a flat strip (except for the ends) of metal to a square would be omitted at the factory. A simple device could be made to ship with the bands so the buyer could make the final bends. The writer has in mind a plan for such a device that could probably be developed into a machine for making metal bands by mass production methods. However, it seems unnecessary to go into such details in this paper which is designed primarily to provide research workers with information that would be useful in the production of metal bands for their own use.

It would be a relatively simple matter also to design pots to be manufactured from sheet metal that should be far superior to the conventional, fragile clay pots. Such metal pots would certainly be no more difficult to construct than galvanized iron pails.

The actual cost of the metal bands herein described was about 1 cent each. This figure may be compared with approximately 0.3 cent (in lots of 1,000) for paper bands at that time. Only the cost of the dies, metal used, and labor were included in the cost of the metal bands. The use of machines such as presses, metal trimmer, etc., in the University of Missouri machine shop was free. The cost would vary considerably depending on wages, machines available, size of the bands, number produced, the gauge of metal used, whether the metal was galvanized iron or aluminum, etc.

No description is given of the dies because it is believed any machinist could take the information presented in this paper and make dies to fit the machines available to him. It might be mentioned that the experimental dies were made of brass and were somewhat worn after the job of making the bands was completed.—LUTHER SMITH, *State College of Washington, Pullman, Wash.*

Book Reviews

NITROGEN IN THE LIFE OF PLANTS AND IN THE AGRICULTURE OF THE USSR

By D. N. Prianishnikov. Moscow-Leningrad: USSR Academy of Science. (Published in Russian.) 197 pages, illus. 1945. 17 Rbs.

THE author opens his monograph with the words of his teacher, Professor K. A. Timiriazev, "There are very few phenomena in which theory and practice are so well bound together as in the study of nitrogen. The purely scientific problems of the economy of nitrogen in plants are inseparable from the practical tasks involving the benefits derived by the cultivation of clover and other legumes."

Prianishnikov expresses hope that on the basis of discoveries made during the past 50 years, his present work will further promote the basic idea of Timiriazev.

The introduction gives the history of the nitrogen problem, compiled with the use of many long-forgotten essays (Albert the Great, Palissi, Gui de Brosse, Glauber, Bacon, Boyle, and others). It is of interest to a layman as well as to a specialist in plant nutrition.

The first part, "The Sources of Nitrogen in Plants", includes the following chapters: Forms of Nitrogen Available to Plants; Nitrogen Metabolism in Plants and the Role Played in It by Ammonia and Amids; Synthesis of the Nitrogenous Organic Compounds in Relation to Nitrates and Nitrites; Assimilation of Free Nitrogen.

The second part is entitled "The Physiological Characteristics of Ammonia and Nitrate Salts as Sources of Nitrogen for Plants". It comprises three chapters: Availability of Ammonia and Nitrate Nitrogen in Relation to the Reaction of the Growing Media, the Concentration of Solution, and the Supply of Carbohydrates; Effect of the Age of Plants on the Rate of Assimilation of NH_4 and NO_3 from the Solution of Ammonium Nitrate; Significance of Various Cations and Anions in the Assimilation of both Ammonia and Nitrates.

Both of these parts present essentially a text-like account of the vital problems in nitrogen nutrition. They are written with a thoroughness characteristic of all of Prianishnikov's papers. A good share of the information is derived from the works of the author himself or from those of his students. Inspite of well-known difficulties in the exchange of scientific literature, Prianishnikov has managed to keep up with current developments. The recent American contributions of P. W. Wilson, D. Burk, Vickery, Eckerson, Nightingale, Shive, and others are incorporated into his book.

The last part of the book, "Nitrogen in the Agriculture of USSR", includes the following chapters: Increase in Crop Production and the Role of Nitrogen in Farming; The Nitrogen Balance in Different Countries of the World; Industrial and Biological Nitrogen; Problems and Perspectives of the Improvement of Nitrogen Balance in USSR; Plans for Manufacture and Use of Mineral Nitrogen Fertilizers; Means of Increasing the Supply of Biologically Fixed Nitrogen; Expected Nitrogen Balance in Agriculture of the USSR; New Possibilities in the Use of Green Manures.

Prianishnikov emphasizes the enormous deficiencies of nitrogen which Russia suffers because of a lack of chemical fertilizers and inadequate cultivation of legumes.

The author sees the practical solution of the nitrogen problem in the combination of both technical and biological means of soil enrichment. He outlines a detailed plan for an enormous production of synthetic nitrogen fertilizers in Russia, utilizing her water power and coal deposits, particularly those of Siberia. In regions where coal is available, he favors the production of cyanamid which, in Russian trials, has proved to be the best fertilizer for repeated applications on podzolic soils.

The book illustrates the unusually broad scope of the writer's knowledge, including chemistry, microbiology, soil science, and agronomy. The volume contains a wealth of information and is invaluable to anyone interested in the various aspects of the nitrogen problem.

The publication of the monograph coincides with the eightieth birthday of the author.—S. A. WILDE, *University if Wisconsin, Madison, Wis.*

EL AZUCAR EN MEXICO

By J. C. Ramírez. Published privately by the Unión de Productores de Caña de Azúcar de la Repûblique México. 373 pages, illus. 1946.

PAPER bound in the fashion of most Latin American publications, this attractive volume presents in detail the background of the annual Mexican production of four million tons of sugarcane, largely used for home consumption and an important phase of Mexican industry. The beginnings were in the 18th Century, although production did not reach a million tons before 1890. The historical, practical, and industrial development of the sugar industry is described with special reference to legislation, conservation, education, industrial organization, and possibilites for the future. Chapters are contributed by A. Sáenz on "La Industria Azucarera Nacional", by J. Blumenkron on "Problemas actuales de la Industria Azucarem," and by E. Sánchez on "Proyecto de Ley para la creación de la Dirreción Técnica de la Industria Azucarera".—A. A. BEETLE, *University of Wyoming, Laronne, Wyo.*

THE PRODUCTION OF TOBACCO

By Wightman W. Garner. Philadelphia: The Blakiston Company. XIII+516 pages, illus. 1946. $4.50.

THIS volume "represents an effort to supply the rather obvious need of a text affording a concise, reasonably comprehensive survey of the essential features of tobacco production and its problems, including interrelations of other phases of the industry. It is written for the use of students in the agricultural colleges and universities, and for agricultural workers and planners who require a broad background of information on the fundamentals of tobacco production."

The book is divided into two parts. Part I deals with botanical relations and gives an historical background of the tobacco industry. Part II deals with all phases of the growing, curing, and marketing

of the crop. Obviously the subject of tobacco is too large to be dealt with in detail in 516 pages, but the author does a remarkable job of fitting in material on the various types of tobacco throughout the book. The viewpoint throughout is very conservative, and the student or teacher who uses the text will find it necessary to do much collateral reading if he is to understand the present situation with respect to many topics.

A bibliography of 16 pages is included so that the student should have no difficulty in finding the original material. The text is well prepared, well printed, and bound. It should prove to be a very valuable reference book for the tobacco specialist and an excellent text for the student of tobacco.—W. D. VALLEAU.

Agronomic Affairs

MINUTES OF THE 1946 MEETING OF THE CROPS SCIENCE DIVISION, OMAHA, NEB., NOVEMBER 20-22

(N.B. Due to circumstances beyond our control, it was not possible to delay publication of the December issue of the JOURNAL in order to include the minutes of the Crops Science Division.)

THE Crops Science Division held one general program and a business meeting and 13 sectional programs, with a total of 83 papers. Professor H. K. Wilson of Pennsylvania State College was elected Vice Chairman, Doctor W. M. Myers of the U. S. Regional Pasture Laboratory, automatically assuming the Chairmanship of the Division. Sectional chairmen were elected as follows: Section 1, D. C. Smith, University of Wisconsin; Section 2, C. J. Willard, Ohio State University; Section 3, E. M. Brown, University of Missouri; Section 4, J. C. Hackleman, University of Illinois; and Section 5, H. R. Albrecht, Purdue University. A committee to organize a Forage Crops Improvement Conference was appointed, consisting of G. W. Burton, *Chairman*, R. P. Knowles, and C. P. Wilsie.

Reports of standing committees were read and approved as indicated below.

VARIETAL STANDARDIZATION AND REGISTRATION

DURING the war years crop breeders bent every effort to get our new varieties that promised additions to national food supplies. As a result there was a faster than usual clean-up on breeding stocks. This year, only three new varieties are offered for registration, one wheat and two oats. These are in process of clearing through the committee.

The Chairman of your committee is now completing 22 years as registration officer in the varietal registration cooperation with the Bureau of Plant Industry, Soils, and Agricultural Engineering, and 18 years as Chairman of this committee. This has been a pleasurable service, but pressure of other duties makes it necessary to relinquish it. In doing so, it is desired to express deep appreciation to other committee members for their helpfulness through the years.

A. C. ARNY — F. N. BRIGGS
H. B. BROWN — L. F. GRABER
H. K. HAYES — T. R. STANTON
R. E. KARPER — T. M. STEVENSON
W. J. MORSE — G. H. STRINGFIELD
J. ALLEN CLARK — H. M. TYSDAL
M. A. MCCALL, *Chairman*

NOMENCLATURE OF GENETIC FACTORS IN WHEAT

YOUR committee, appointed primarily for the purpose of correlating and stimulating the genetic research on wheat, decided first to make a survey of the work now being done. A request was made to the regional coordinators of the wheat projects for a summary of the wheat genetics work which was being done in each of their areas. Only a part of these reports have been received to date. As soon as these reports are received it is tentatively planned to contact the individual workers in an attempt to stimulate, develop, and correlate genetic research.

J. B. Harrington
K. S. Quisenberry
E. R. Sears
S. P. Swenson
E. R. Ausemus, *Chairman*

TURF

THE production and management of turf represent specialized uses of grass which are of interest to more taxpayers than any other agricultural activity, yet have received practically no attention from most of the agencies engaged in agricultural research. Much of the information at the present time has had to be adapted from pasture and forage crop research. This can lead to false conclusions in view of the specialized uses and adaptations of grasses for turf purposes. Among the more important uses of grass for turf are lawn areas around homes, estates, hospitals, and industrial plants, cemeteries, parks, golf courses, other recreational areas, athletic fields, drill and parade grounds, roadsides, and airfields. The value of roadside turf cannot be overemphasized from the standpoint of safety and the control of soil erosion. The development of certain classes of air field is moving in the direction of turf runways which merit especial attention. The lack of reliable information has resulted in a tremendous net loss of time, energy, funds, and materials.

Recognizing the scope of the turf industry and the magnitude of the problems involved, the committee recommends:

1. That consideration be given to the establishment of a turf research program at each existing agricultural research agency which will meet the needs of the area involved. This would add to the sum total of our knowledge in this specialized field and would serve as important media for the training of students of agriculture. An appreciation and an accurate working knowledge of turf management is especially important to students who expect to develop professionally and who may be expected to give advice in the field of turf. This includes the research man, the vocational teacher, the county agent, and all others who provide service such as seedsmen, fertilizer dealers, and chemical companies which supply herbicides, insecticides, and fungicides. To graduate a student in agriculture without having given him an opportunity to learn of the specialized uses of grass represents an omission on the part of the colleges to complete the training of their students.
2. That the extension services be encouraged to provide the same type of services in the field of turf that are now provided for other phases of agriculture.
3. That the Turf Committee of the Society be charged with the responsibility of making a detailed survey of the size and the scope of the turf industry, and with reporting the facts to the Society at its next annual meeting.
4. That provision be made for a Turf Section at the next annual meeting of the Society.

H. B. Musser
H. R. Albrecht
M. E. Farnham
F. V. Grau, *Chairman*

RESOLUTIONS

THE Resolutions Committee during the summer of 1946 had opportunity to meet with the North Central Association of Experiment Station Directors at Peoria, Ill., to present to them a proposal that formal approval be granted for holding Crop Science Conferences. The Association approved the holding of

such conferences, providing that specific requests for each individual conference pertaining to a particular crop were made in advance and approved by the Administrative Advisor for the Plant Sciences.

S. S. ATWOOD
J. B. WASHKO
I. J. JOHNSON, *Chairman*

HUGH GARRY MYERS[1]

HUGH Garry Myers, Associate Professor of Soils at Kansas State College, died on November 21, 1946, at the Brooklyn Naval Hospital, Brooklyn, N. Y. He was on leave of absence from his duties at Kansas State College as a Lieutenant (J.G.) in the Navy at the time of his death. Mr. Myers was born at Barnard, Kansas, August 17, 1916. He graduated from Kansas State College with honors in 1938 and obtained his Master of Science degree from the University of Kentucky in 1941. After receiving his Master's degree he spent one year as an instructor in Soils at the University of Kentucky. While there he made a study of the excretion of nitrogen from legume roots. In 1942 he became Agent, Bureau of Plant Industry, U.S.D.A., in charge of Dry Land Farming Investigations at the Garden City Agricultural Experiment Station which is a branch of the Kansas Agricultural Experiment Station. In November, 1943, he became a member of the teaching and research staff of Kansas State College. While in this position he made studies and published on the influence of legumes on the physical properties of soils. He took leave of absence from Kansas State College in July, 1944, to enter the armed service where he contracted his fatal illness.

Hugh Myers was married in 1938 and is survived by his wife and two children, Judy and Gary, who reside at their home in Manhattan, Kansas.

The untimely death of this promising young scientist is a regretable loss to the field of soils investigations, a loss which is keenly felt by those who knew him best for his genial personality, clear thinking, and indefatigable work.—H. E. JONES.

THE UNIVERSITY OF NORTH CAROLINA INSTITUTE OF STATISTICS

IN JULY, 1946, the University of North Carolina completed the organization of the all-University Institute of Statistics, with Gertrude M. Cox as Director and W. G. Cochran and Harold Hotelling as Associate Directors. The Institute is composed of two departments, *viz.*, the Department of Experimental-Statistics at North Carolina State College at Raleigh, and the Department of Mathematical Statistics at the University of North Carolina, Chapel Hill. The teaching and portions of the research work are handled directly by the two departments, each of which is a regular unit of its respective school.

The Institute had its inception in January, 1941, when Miss Cox was invited to organize a department at North Carolina State College for teaching, consulting, and research in statistics, particularly in the

[1]Received too late to be incorporated in the report of the Resolutions Committee, pages 1129 to 1131, of the December, 1946, issue of the JOURNAL.

fields of biological and social sciences. During the following years the scope of this Department was considerably enlarged, and at the start of the 1946–47 academic year included sections for plant science (Professor J. A. Rigney, Assistant Professor H. F. Robinson, Instructor Jeanne Freeman), animal husbandry (Associate Professor H. L. Lucas), economics (Associate Professor R. L. Anderson), engineering and industry (Associate Professor Paul Peach), chemistry (Instructor R. J. Monroe), and methodology (Instructor Sarah Porter). There is an active section devoted to meteorology, under the direction of C. E. Lamoureux and G. P. Weber of the U. S. Weather Bureau, and another in the field of agricultural economics under W. A. Hendricks, A. L. Finkner, F. E. McVay, Blair Bennett, and Emil Jebe of the U. S. Bureau of Agricultural Economics.

The Department of Mathematical Statistics at Chapel Hill, which was organized in the summer of 1946, was established to cope with the need for more extensive research in theoretical statistics. Professor Harold Hotelling is Head of this Department and is assisted by Professor M. S. Bartlett, visiting from Cambridge, England, Associate Professors P. L. Hsu, W. G. Madow, and H. E. Robbins, and Instructor Edward Paulson. Doctor Madow is at present on leave at the University of Sao Paulo in Brazil.

The two departments are offering course work towards M.S. or Ph.D. degrees in statistics and minor work for degrees in other sciences. These courses are for the benefit of those preparing to teach statistics, to develop statistical theory, to become statistical consultants in various fields, and for research scholars in other sciences who want a practical working knowledge of statistical theory.

In addition to teaching, staff members of the Institute devote a major part of their time to consulting and research. Requests for assistance continue to come from all phases of biological research, from investigators in economics and in sample surveys, and from various industrial manufacturing and service organizations.

The Institute is financed by state appropriations and funds accruing from cooperative agreements with federal and industrial agencies. Two substantial grants from the General Education Board were made available to inaugurate this program. On a limited basis, the Institute accepts research and consulting assignments from commercial firms and from government agencies. It is cooperating with other colleges and universities in promoting the advantageous use of efficient statistical methods in research, in advancing the theory of statistics, and in the training of competent statisticians.

—J. A. Rigney.

NEWS ITEMS

The University of Wyoming Agronomy Division is instituting a new program in Range Management, including two new, full-year, advanced courses in Range Utilization and Improvement and Range Plants. The program is being developed by A. A. Beetle, formerly of the Agronomy Division, University of California, and R. L. Lang.

DOCTOR W. E. DOMINGO, formerly Agronomist with the U. S. Dept. of Agriculture, Beltsville, Md., working on special crops, has resigned to become Director of agronomic work for the Baker Castor Oil Company, Los Angeles, Calif.

A

DOCTOR C. G. G. J. VAN STEENIS, Senior Botanist of the Department of Economic Affairs, Buitenzorg, Java, arrived in the United States on December 16 to discuss, with American colleagues, his plans for the *Flora Malesiana*, a new flora of the Malaysian Archipelago, now being prepared on an international, cooperative basis. He is accompanied by Mrs. van Steenis, who has almost completed the first volume of the flora, an extensive historical introduction.

A

Biologia, a monthly newsletter supplement to *Chronica Botanica*, has just recently made its appearance under the editorship of Doctor Frans Verdoorn. It is hoped that it will fill a need for a newsletter reporting quickly on developments of professional and international interest, and that "it will yield some influence in uniting workers in the various branches of the pure and applied plant and animal sciences throughout the world." *Biologia*, which is to be kept small and informal, will be sent free to all regular subscribers to *Chronica Botanica* (annual subscription $7.50), or subscriptions will be accepted for the newsletter alone at the rate of $4.00 a volume, covering two years. Communications should be addressed to Doctor Verdoorn, P. O. Box 151, Watham 54, Mass.

JOURNAL
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Effect of Straw and Cornstalks on the Yield of Soybeans[1]

A. J. ENGLEHORN, K. LAWTON, H. R. MELDRUM, AND A. G. NORMAN[2]

ON the basis of two greenhouse experiments it has been stated by Pinck, Allison, and Gaddy (2)[3] that growth and nitrogen uptake by soybeans are depressed by incorporation of straw in the soil at substantial rates. The addition of fertilizer nitrogen may counteract the effect of the straw, but may also reduce the amount of nitrogen fixed by the crop. The latter is not especially important, however, if the yield of beans is increased.

Three field experiments carried out by us in the course of extended studies on the nitrogen nutrition of soybeans have included straw or cornstalk residue treatments, with and without additions of nitrogen fertilizer. The results of these expressed as yields of threshed soybeans per acre are not in accord with the conclusions derived from the greenhouse experiments cited above. In addition to the straw or residue plots these field experiments included a variety of nitrogen treatments which will form the subject matter of a later communication.

EXPERIMENT 1, AGRONOMY FARM, AMES, 1943

The soil type was Clarion loam. The Richland variety was inoculated and planted in 34 inch rows on May 24. Ten replicates of treatments were arranged in two contiguous 5×5 Latin squares. Straw was plowed under on five plots in each square at the rate of 4 tons per acre on May 4 followed by disking. Sulfate of ammonia was applied in split plot applications of 300 pounds per acre broadcast between rows on July 27.

From the data in Table 1 it may be seen that no decrease in soybean yield was caused by spring plowing of straw at a heavy rate. Furthermore, the straw did not cause any significant change in the nitrogen content of the soybeans, or the nitrogen in the crop per acre. The effect of a midseason nitrogen application on the straw plots was however substantial and highly significant.

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[1]Journal Paper No. J-1390 of the Iowa Agricultural Experiment Station, Ames, Iowa, Project No. 789. Received for publication August 20, 1946.

[2]Research Assistant Professor, Research Associate, Research Assistant Professor, and Research Professor, respectively.

We are indebted to W. G. Cochran for assistance with the design and analyses of these experiments, and to G. M. Browning and W. H. Fuller who participated in certain phases.

[3]Figures in parenthesis refer to "Literature Cited", p. 92.

TABLE 1.—*Effect of incorporation of straw by spring plowing on yield of soybeans with and without midseason application of nitrogen fertilizer, Agronomy Farm, 1943.*

	No straw		Straw incorporated	
	No nitrogen	Midseason nitrogen	No nitrogen	Midseason nitrogen
Yield of soybean, bu. per acre...	29.34	28.24	30.89	34.10
N content of soybeans, %......	6.15	6.15	6.16	6.24
N in soybeans, lbs. per acre....	109.1	104.4	114.4	128.0
N in soybean straw, lbs. per acre.	15.3	15.2	16.4	17.2

Least significant difference (5%) between bean yields = 1.74 bu.; between N content of bean = 0.106%; between N in beans = 9.3 lb.; between N in straw = 1.2 lb.

EXPERIMENT 2, CLARINDA, IOWA, 1944

The soil type was Marshall silt loam. The Mukden variety was inoculated and planted in 40-inch rows on May 20. Ten replicates of treatments in paired blocks with and without cornstalk residues were disked and plowed under. Cornstalk residues were from a 60-bushel crop on the same area in the previous season and were raked from no cornstalk plots onto cornstalk plots so that the latter received twice the normal amount. Various nitrogen applications were made on both cornstalk and no cornstalk plots at intervals during the season.

In this experiment (Table 2) the incorporation of cornstalks at a rate twice that which might be considered normal for the area did not significantly change the yield of soybeans. Similarly the presence of cornstalks did not result in any difference in the mean yields of a large number of plots which received nitrogen fertilizer in various amounts during the growing season.

TABLE 2.—*Effect of incorporations of cornstalks by spring plowing on yield of soybeans with and without nitrogen fertilizer applications, Clarinda, 1944.*

Treatment	Mean yield of soybeans, bu. per acre
No cornstalks (10 replicates)....................	21.46
Cornstalks (10 replicates)......................	21.19
No cornstalks (mean of all N treatments, 70 plots)	24.16
Cornstalks (mean of all N treatments, 70 plots)....	23.71

Least significant difference (5%) = 0.72 bu. per acre between cornstalk and no cornstalk plots with or without nitrogen applications.

EXPERIMENT 3, AGRONOMY FARM, AMES, 1944

The soil type was Clarion loam. The Richland variety was inoculated and planted in 34-inch rows on May 12. Twelve replicates were arranged of treatments in paired blocks with and without incorporation of straw. Oat straw was plowed under at the rate of 2 tons per acre on Nov. 21, 1943. Broadcast nitrogen applications were made to straw and no-straw blocks at the rate of 250 pounds of sulfate of ammonia per acre at time of plowing or at time of planting.

The mean yields of soybeans on these plots are given in Table 3. It will be seen that straw incorporation by late fall plowing did not reduce the yield, but in fact resulted in an increase that just exceeded significance at the 5% point. Applications of nitrogen fertilizer either at time of plowing or at planting did not produce any yield increase either on straw or no-straw plots. The mean of all 36 straw plots exceeded that of all the no-straw plots by 1.5 bushels per acre.

TABLE 3.—*Effect of incorporation of straw by late fall plowing on yield of soybeans with and without application of nitrogen fertilizer, Agronomy Farm, 1944.*

Treatment	Nitrogen, 50 lbs. per acre	Mean yield of soybeans, bus. per acre
No straw	0	32.16
No straw	Plowing	32.16
No straw	Planting	31.63
Straw	0	33.64
Straw	Plowing	33.86
Straw	Planting	32.98

Least significant difference (5%) between straw and no straw plots = 1.44 bu.; between nitrogen and no nitrogen plots = 1.06 bu.

DISCUSSION

In none of the three field experiments reported did any decrease occur in yield of threshed soybeans as a result of plowing under straw or cornstalk residues. The prairie soils on which these experiments were laid out may be considered to be representative of much of the land in the north central and southwest parts of the state, respectively. They no doubt have a higher content of available nitrogen than the Sassafrass sandy loam used in the greenhouse studies of Pinck, *et al*, (2). There is now evidence which points to the conclusion that the soil nitrogen which becomes available during midseason may in large measure determine the ultimate yield of inoculated soybeans (1). Incorporation of straw at time of plowing would have its main effect on the amount of nitrogen available early but unless added in excessive amounts would not be likely to reduce the midseason supply.

Apart from the higher nitrogen content of the prairie soils, it is believed that the different criterion used for expressing yield may be a partial explanation of the apparent divergency of our findings from those of Pinck, *et al*, (2). In our experience the yield of soybeans is more closely correlated with the amount of nitrogen in the crop than with the total dry weight of the plants. Moreover the soybean plants harvested by Pinck, *et al*, (2) were presumably quite immature, especially in the "Summer" experiment which was terminated at 56 days.

The results of these field experiments make it probable that under Iowa conditions soybeans may follow a crop leaving a substantial amount of carbonaceous residues without reduction in yield and without the necessity of supplying additional nitrogen to meet the requirements of the decomposing residues.

SUMMARY

The incorporation of straw or cornstalk residues into prairie soils of average fertility (Clarion loam and Marshall silt loam) did not result in any reduction in the yield of threshed soybeans in three well-replicated field experiments.

LITERATURE CITED

1. NORMAN, A. G. Inoculation and nitrogen nutrition of soybeans. Soybean Digest, 4:41–42. 1944.
2. PINCK, L. A., ALLISON, F. E., and GADDY, V. L. The effect of straw and nitrogen on the yield and quantity of nitrogen fixed by soybeans. Jour. Amer. Soc. Agron., 38:421–431. 1946.

Significance of Moisture Translocation From Soil Zones of Low Moisture Tension to Zones of High Moisture Tension by Plant Roots[1]

GAYLORD M. VOLK[2]

PLANTS absorb water from the soil by means of tension or suction force developed within the plant roots. Opposing tension is built up in the soil as the available moisture approaches depletion, and absorption ceases when these forces become equal. A plant growing under normal conditions draws moisture from both the surface and the subsoil, but the surface soil is usually depleted of available moisture first, mainly because of root concentration and surface evaporation. It is conceivable that evaporation from the surface soil could develop a soil moisture tension higher than that in the roots located in it if the plant had roots also in moist subsoil of low moisture tension to supply the needed water. The tendency then would be toward withdrawal of moisture from the roots lying in the surface soil and intake of moisture from the subsoil.

Breazeale (1)[3] and Breazeale and Crider (2) presented data which indicated that this phenomenon did take place, and that it permitted plants to maintain or develop roots in soil so dry as to be otherwise unfavorable for root growth. Breazeale implied that, given the proper conditions, a plant would actually build up the soil moisture to the wilting range. However, Davis (3) presented data to show that corn plants depleted soil moisture to below the permanent wilting point in the vicinity of the crown even though adequate moisture was supplied to roots at a distance of 4 feet from the crown of the plant. Hendrickson and Veihmeyer (5) stated that their results indicate that roots will not grow into soil which contains less moisture than the permanent wilting percentage. Breazeale also presented data to show that potassium could be absorbed by plants from soil at the wilting point.

It was the purpose of this investigation to obtain further information on the significance of soil moisture translocation through plant roots with respect to the maintenance or build-up of soil moisture, the absorption of mineral nutrients from soil at and below the permanent wilting point, and the development of roots into dry soil areas.

RELATION OF THE PERMANENT WILTING POINT TO THE CRITICAL SOIL MOISTURE

The term *critical soil moisture* is used in this report to indicate the apparent level to which a turgid plant will reduce the soil mois-

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. Received for publication August 26, 1946.

[2]Chemist, Florida Agricultural Experiment Station. The work was initiated at the Florida Agricultural Experiment Station and completed under a General Education Board fellowship at the University of Wisconsin. The writer is indebted to Professor Emil Truog and Dr. M. L. Jackson for their interest in the work and especially for their helpful criticism in preparation of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 106.

ture in contact with one portion of its root system where soil moisture is not replenished, while the remaining portion has an adequate supply.

DESIGN OF EXPERIMENT

The critical soil moisture percentage was determined by means of a corn plant having a divided root system which was developed in place over the edge of a half-gallon tin container filled with soil and buried in a 2-gallon pot, flush with its top, and otherwise filled with quartz sand. The soil to be examined was placed in the container, wet up to optimum, and then several kernels of corn were planted in the soil against one side of the container. The kernels were inserted point down to a depth of ¼ inch below the edge. The top edge of the tin above the kernels was then covered with a quartz sand bond about 1 inch in depth, thereby providing a common junction between the soil in the tin and the sand outside, through which the seedling could emerge and through which roots from the upper nodes could penetrate into either the soil or the surrounding sand. The quartz sand was then thoroughly moistened and the entire pot covered with wax paper to maintain favorable moisture conditions. When the coleoptiles emerged, they penetrated the wax paper. The seedlings were thinned to two per container and permitted to continue growth in that manner until they developed well divided root systems. This took 6 weeks from the date of seeding. At this time the sand bond was brushed away to expose the edge of the tin, the soil brought up to optimum moisture, and the surface sealed with paraffin and beeswax. A sub-irrigation system consisting of a glass tube imbedded in a small amount of sand was used in watering the soil during development of the seedlings up to this stage. No water was added to the soil after sealing, but the quartz sand into which one portion of the roots had developed was kept moist. The corn was allowed to continue growth for another 6 weeks, then the seal was removed and moisture determinations were made of the soil.

In a separate series, the permanent wilting point of the soils was determined with corn seedlings after the manner of Hendrickson and Veihmeyer (6).

RESULTS AND DISCUSSION

The following data are the average of four replicates. The permanent wilting point for Plainfield sand was found to be 1.52% and the critical soil moisture 1.70%, or 1.12 times the former. The permanent wilting point for Clyde silt loam was found to be 8.91% and the critical soil moisture 9.91%, or 1.11 times the permanent wilting point. It is logical to expect the critical soil moisture to be higher than the permanent wilting point, because the latter was developed under a tension at equilibrium with a plant having a much greater water deficit than was the case with the critical soil moisture. Sufficient roots were present in all portions of each container to reduce the soil moisture to equilibrium in 6 weeks' time, but it is conceivable that they still could be insufficient in number to prevent the drop of soil moisture below this point if evaporation from the soil was significant in amount as a result of an ineffective seal. Therefore, the values obtained for the critical soil moisture are probably a minimum.

SIGNIFICANCE OF ROOT DEVELOPMENT INTO SOILS BELOW THE PERMANENT WILTING POINT

DESIGN OF EXPERIMENTS

Two trials were made using somewhat different techniques. The first consisted of eight single-plant replications to compare the effect on the plant of root growth into Plainfield sand of very low fertility to the effect of root growth into

the same soil to which fertilizer had been added at the rate of 1,000 pounds of 5–20–17 per acre on the soil weight basis. The fertilizer was made up from KNO_3 and $Ca(H_2PO_4)_2.H_2O$. Thirty-two pounds of magnesium were added as the sulfate. Both treatments included precipitated calcium carbonate at the rate of 1,000 pounds per acre because the initial soil pH was 5.5.

Each plant was grown in a two-compartment culture of the type shown in Fig. 1. Seedlings were established by planting corn directly in the channel of each container. A complete nutrient solution was used in the quartz sand in the outer pot as a source of nutrients to the seedlings, while tap water was used in the channel. Protection against drying of the sand in the channel and at the slot outlet was provided by wax paper covers.

Six weeks after planting, the seedlings had developed a root system through the slot into the outer pot. At this time the embankment was washed away, and the sand in the outer pot thoroughly flushed with tap water to remove soluble nutrients. The sand in the channel was allowed to dry out and the channel was removed. The roots which had developed in the channel were partially freed of the dry sand by gentle tapping, and the slot in the side of the container closed by

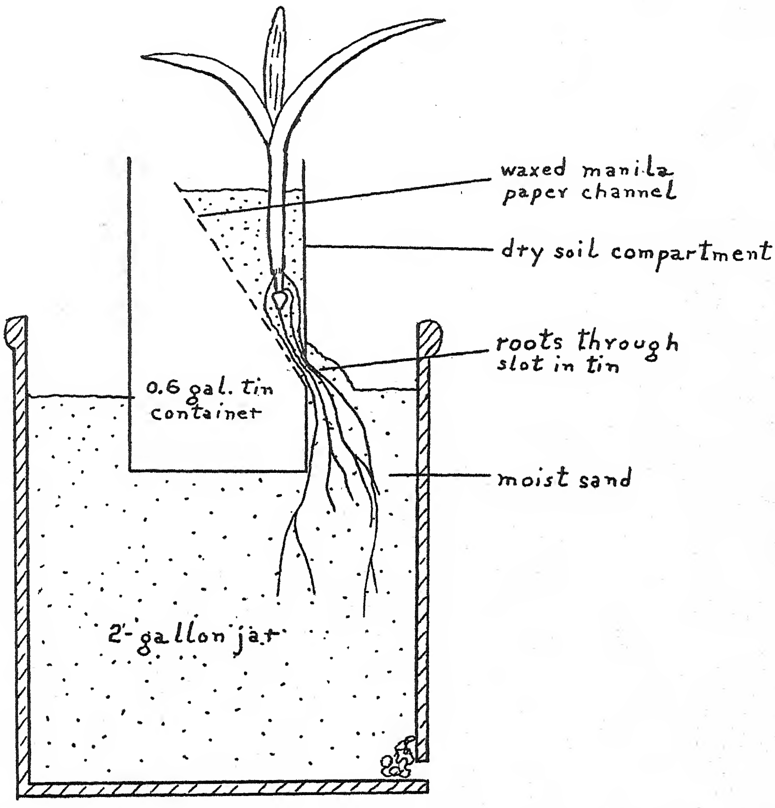

FIG. 1.—Type of culture used to establish seedlings with roots divided between wet sand and dry soil. When a good set of roots had grown through the slot into the outer or wet compartment, the paper channel was removed and dry soil packed into the inner compartment around the crown of the plant. The sand covering the slot was removed to expose the roots and slot, and the slot and the top of the inner compartment sealed around the plant roots and stem. Subsequent root growth in the inner compartment took place in the dry soil.

bending the edges of the tin back into place against the roots. In order to eliminate bias in selection of plants for the two different treatments, the plants were rated from 1 to 16 on the basis of size and root development. They were then paired in order of their rating and one plant of each pair given the same treatment. The order of treatment application in each successive pair was alternated.

The soil was packed gently into the inner compartments around the exposed crowns of the plants, and the tops of these containers closed with water-proof cellophane. No special attempt was made to seal around the stems of the plants because it was feared that carbon dioxide might develop to toxic concentration if the seals were too tight. The containers were shaded and the quartz sand kept moist at all times.

After 6 weeks' time the dry soil compartments were opened for observation of root development. The plant tops were weighed and analyzed. The results are reported in Table 1.

TABLE 1.—*Response of corn to root growth into air-dry Plainfield sand with and without fertilizer in a divided root system culture, single plant experiment.*

Dry compartment treatments, eight replicates	Yield		Plant top analysis					
			Phosphorus		Potassium		Nitrogen	
	Grams green weight	Grams dry weight	%	Mgm total	%	Mgm total	%	Mgm total
1, no fertilizer added	38.28	6.91	0.205	14.1	0.748	50.4	0.966	63.8
2, fertilizer added	31.38*	5.31*	0.202	10.6*	0.836**	43.1	1.034	53.8*

*Differences resulting from treatments significant at the 1% point.
**Differences resulting from treatments significant at the 5% point.

In the second experiment, the general plan of seedling development was the same, except that full gallon inner containers with the tops cut away were used, and slots were cut in both of the wide faces so as to accommodate two channels instead of one. Also, mineral nutrients for development of the seedlings were supplied by means of a soil in the outer container rather than quartz sand and nutrient solution. It consisted of 90% Plainfield sand of low fertility and 10% Clyde silt loam of high fertility. The channel filling and outside embankment over the slots were quartz sand. Five kernels were planted in each channel and later thinned to three seedlings or six per container.

In order to compensate for variations in plant size at the start, the pots were arranged in order of decreasing plant size and grouped into fours for randomization of the four treatments. The following four dry compartment mediums were used in triplicate: (a) Plainfield sand of low fertility; (b) Plainfield sand plus fertilizer equal to a 1,000 pound per acre rate of 5–7–5 made up from ammonium nitrate and mono-potassium phosphate; (c) fertile Clyde silt loam at 6.43% initial moisture content; and (d) fertile Clyde silt loam at 7.92% initial moisture content.

The seal over the top of the inner compartment consisted of paraffin and beeswax. Plasticene was used over the slots. The experiment was terminated 6 weeks after differentiation of treatments. Results are presented in Table 2 and Fig. 2.

EFFECT OF SOIL TYPE AND MOISTURE CONTENT ON ROOT DEVELOPMENT

The first experiment (Table 1) did not furnish significant data on root development, apparently because of an inadequate seal over the soil. Root growth into the dry soil was present but relatively limited in all instances, with no apparent visual differential effect of treatments.

TABLE 2.—*Development of corn roots in soils below the permanent wilting point in divided root system culture and resultant effect on soil moisture and plant growth and composition, multiple plant experiment.*

Dry compartment soil and treatment, 3 replicates	Percentage soil moisture at harvest			Grams dry weight of roots less ash*	Grams dry weight of tops	Plant top analysis					
						Phosphorus		Potassium		Nitrogen	
	Above root zone	Root zone	Below root zone			%	Mgm total	%	Mgm total	%	Mgm total
1, Plainfield sand, no fertilizer, 0.43% H_2O	0.79	0.98	0.74	1.91	16.7	0.180	29.5	1.03	172	0.573	95
2, Plainfield sand, fertilizer added, 0.43% H_2O	0.69	1.02	0.77	1.51	16.6	0.187	31.2	1.13	189	0.573	96
3, fertile Clyde silt loam, 6.43% H_2O	5.29	6.70	5.91	2.50	15.4	0.192	29.2	1.36	210	0.663	101
4, fertile Clyde silt loam, 7.92% H_2O	5.65	7.13	6.26	4.65	20.1	0.162	32.5	1.32	265	0.663	133
L. S. D. at .05†				1.25	3.1	0.022	3.6	0.26	26	0.064	19
L. S. D. at .01†				1.89	4.7	0.033	5.5	0.40	40	0.096	29

*Determined by ignition loss of washed roots corrected for ignition loss of soil residue obtained.
†Least significant difference at odds of 19:1 and 99:1, respectively, by analysis of variance. L. S. D. for the 1% point for percentage soil moisture between zones are 0.11 for treatments 1 and 2 and 0.15 for treatments 3 and 4.

Results of the second experiment are presented in Fig. 2 and Table 2. There was remarkable evidence of the greater vigor of root development into the Clyde silt loam as compared to the Plainfield sand. This might have been the result of more favorable initial moisture tension in the former, because the Plainfield sand was used at the high tension of the air-dry state, while the Clyde silt loam was used at moisture levels intermediate between the air-dry soil moisture content of 4.55% and the critical soil moisture level of 9.91%. This was done with the intention of partially equalizing the greater difference of 5.36 between the air-dry moisture percentage and the critical soil moisture for the Clyde silt loam as compared to the smaller difference of 1.27 for the Plainfield sand.

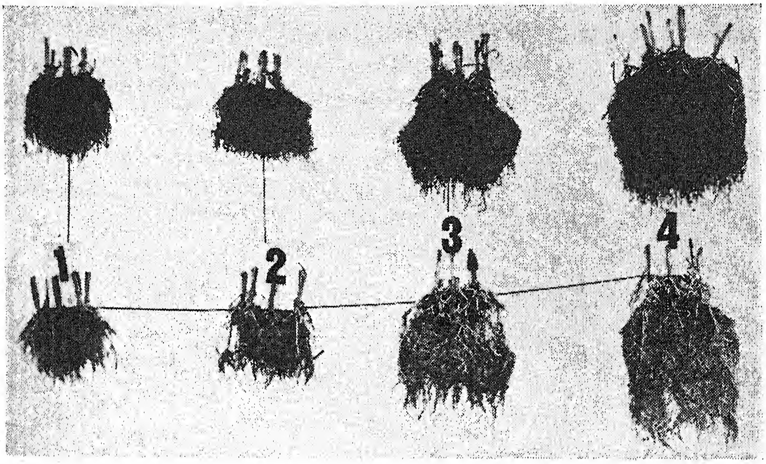

FIG. 2.—Effect of various soil treatments in divided root system culture on root growth into dry soil. The roots represent the inner or dry compartment growth before and after washing. Inner (dry) compartment treatments: 1, Air-dry Plainfield sand of low fertility; 2, air-dry Plainfield sand with complete fertilizer; 3, fertile Clyde silt loam with 6.43% initial moisture; and 4, fertile Clyde silt loam with 7.92% initial moisture. Moisture and part of the mineral nurients were supplied by an outer (wet) compartment.

The roots developed in the Plainfield sand were much more coarse than those developed in the Clyde silt loam, which accounts for the fact that the visual differences are more outstanding than the weight differences reported in Table 2. In no instance did isolated roots extend beyond the common front of the mass of roots penetrating the dry soil. In neither treatment was the downward extension of the roots limited by the depth of the container because from 4 to 6 inches of root-free soil were found in the bottom of every container. This is excellent evidence that the moisture content of that horizon was below the critical point for favorable root development, and that root growth took place only as a result of cooperative build-up of soil moisture by a common front of elongation of numerous roots. The lack of opportunity for numerous roots to function cooperatively

in the build-up of moisture apparently is the explanation for the negative results obtained in the type of culture used by Hendrickson and Veihmeyer (5).

The higher moisture content of the Clyde silt loam in treatment 4 as compared to treatment 3 resulted in greater root growth. The fact that a relatively small increase in the initial moisture content of the soil produced nearly double the root growth is indicative of the difficulty encountered by the plants in building up the soil moisture and competing with evaporation loss. There was an actual drop in soil moisture percentage from the initial 7.92 down to 7.13 in the root zone of treatment 4, but the final moisture percentage in the bottom of the container was only 6.26, or 0.87% below that of the root zone. This indicates that considerable evaporation loss around the seals took place so that the minimum moisture content during early stages of root development was actually much lower than the initial percentage given.

The fact that root growth into the Plainfield soil to which fertilizer had been added was less than growth into unfertilized Plainfield suggests toxicity of some type. This is further emphasized by data presented in a later section.

EFFECT OF ROOT GROWTH ON SOIL MOISTURE BUILD-UP

Root development in the dry compartments of the second experiment (Table 2) took place at an intermediate depth in the container, with root-free soil both above and below the root zone. Soil moisture samples were taken of the three zones. That of the root zone was obtained by shaking the mass of roots and collecting a sample from the free soil shaken out. This did not represent the true soil moisture condition as well as could be desired, because the true soil moisture content with which the roots were in equilibrium probably would be represented by a small cylinder of soil around each root. A texture segregation process would also function in the method used, because the soil retained by adherence to the surfaces of the roots could hardly be representative of the mass. Despite the above factors, an increase in soil moisture was exhibited with all treatments except No. 4. The fact that the soil moisture content both above and below the root zone in the Clyde silt loam was lower, indicates that condensation of moisture from an external source as a result of temperature changes could not have been the reason for the increase. Therefore, it is assumed that the moisture build-up was the result of translocation from the moist soil compartment. The drop in moisture content below the initial level for the Clyde silt loam in the horizons both below and above the root zone shows that there actually was considerable moisture loss through evaporation around the seals, and that the build-up in the root zone was in spite of this loss. Treatment 4 actually maintained a moisture level 0.87% above the final level in the bottom of the tin container. As previously stated, loss of moisture from the soil in the bottom of the tin probably took place before root development in the dry soil was significant.

The high moisture tension of air-dry soil was partially alleviated for the Clyde silt loam by the initial moisture addition, however in

the case of the Plainfield sand this was not done, with the consequence that a higher vapor pressure deficit existed throughout the dry soil compartment. Moisture withdrawn from the roots evidently moved in part, probably as vapor, to the soil still at the higher tension, with the result that a general increase occurred throughout the container. The average percentage soil moisture content outside of the root zone in the Plainfield sand was changed from 0.43 up to 0.75 which was a 75% increase.

It is obvious that reliable negative data on the ability of roots to translocate moisture would be difficult to obtain because of heterogeneity in the soil and the difficulty of preventing evaporation loss. Root resistance to the transpiration stream would explain the reduction of soil moisture to the wilting point in the vicinity of the crown of a plant before moisture was depleted at greater distances away, but it is questionable that a turgid plant can reduce the soil moisture to below the wilting range or that a wilted plant can reduce it to a tension in excess of that in the plant.

EFFECT OF ROOT GROWTH INTO SOIL BELOW THE PERMANENT WILTING POINT ON PLANT GROWTH AND COMPOSITION

The effect of development of roots in dry soil on the plant top growth and composition is indicated by the data in Tables 1 and 2 obtained from the single and multiple plant experiments, respectively. Table 1 shows the comparison of dry Plainfield sand of low fertility to dry Plainfield sand to which a heavy application of fertilizer had been made. In every instance of eight replicate pairs, both the green weight and the dry weight of the member of the pair of treatments growing in the more fertile soil was lower. This was accompanied by a higher percentage of potassium in the plant but a lower total quantity. Nitrogen followed the same trend. Phosphorus was higher in total amount where no fertilizer had been added, but the percentages were practically identical. The differences in green weight, dry weight, total phosphorus, and total nitrogen between the two treatments are statistically significant at the 1% point according to the ratio of the mean to the standard error. The difference in percentage potassium is significant at the 5% point. In so far as both nitrogen and potassium were higher in the smaller plants, these elements could hardly have been primary limiting factors. It is possible that toxicity resulting from fertilizer addition was involved, or that the phosphorus was limiting because it could not be taken up as readily in the presence of the added salts. The percentage of phosphorus in the plant is practically identical for the two treatments, but the total quantity absorbed is much higher in the unfertilized pots where the greater dry weight was obtained.

The difference in effect of the fertilized and unfertilized Plainfield sand in the multiple plant experiment presented in Table 2 is similar in certain respects to the above. There is some evidence of greater nutrient up-take from the fertile soil than from the infertile. No apparent toxicity as a result of the higher fertility level existed other than the depressed root growth previously mentioned. The fact that the total salts added as fertilizer in the case of the multiple

plant set-up was much lower than the addition to the single plant set-up, and that the former was able to build up a better moisture condition as evidenced by root growth, may account for this difference in the two experiments. It must also be remembered that the external source of fertility was supplied throughout the multiple plant experiment (Table 2), whereas it was removed at the time of treatment differentiation in the single plant experiment (Table 1).

The response of the corn to the fertility in the Clyde silt loam, especially in the higher moisture level as compared to the Plainfield sand, is noteworthy. Here there appears to be positive evidence that phosphorus was not being assimilated from the dry soil as readily as was nitrogen and potassium. There was a definite drop in percentage in the plant and little increase in total quantity with increase in total dry weight. Potassium and nitrogen were higher in both percentage and total in the plants growing in the Clyde silt loam as compared to the Plainfield sand. Two factors might be responsible. The Clyde silt loam was highly fertile without the possibility of toxicity from soluble salts, and the moisture conditions apparently were better.

It appears from the data that plants will develop roots into an environment detrimental to the plant with respect to soluble salts, and that nitrogen and potassium but not phosphorus can be taken into the plant in significant quantities at moisture levels below the wilting point. This is in agreement with the findings of Dean and Rubins (4) that phosphorus does not respond readily to contact feeding of the type found by Jenny and Overstreet (7) to be successful for cations.

NUTRIENT UPTAKE FROM SOILS NEAR THE PERMANENT WILTING POINT BY PLANTS WITH ESTABLISHED AND TRANSPLANTED ROOTS

There is little doubt but that the build-up of soil moisture in soils significantly below the permanent wilting point is a slow process during which the rate of nutrient absorption is relatively low as compared to the rate of uptake under conditions in which there is no need for moisture build-up but only maintenance against limited evaporation. The optimum condition under which to study nutrient intake in the absence of available water would be one in which the soil had been reduced to the critical soil moisture by the plant and no evaporation loss from the soil existed. The following experiments do not accomplish this ideal but indicate what the efficiency of such a culture might be.

DESIGN OF EXPERIMENT FOR NITROGEN ABSORPTION

The experiment was carried out in triplicate. It consisted of single and double compartment cultures using transplanted millet. Compartments consisted of 1-quart friction top cans placed side by side. Treatments were as follows: 1, Undivided root system in quartz sand irrigated with N-free nutrient solution; 2, root system divided between N-free nutrient solution sand culture and Norfolk loamy fine sand high in organic compost in an open top compartment; 3, identical with treatment 2 with the exception that the friction top of the container was put in

place and punched with a dozen nail holes; 4, identical with treatment 3 with the exception that the top was unpunched; 5, all roots growing in the Norfolk soil plus organic compost at optimum moisture content.

The above experiment was designed to make nitrogen the critical factor with respect to mineral nutrition. The Norfolk loamy fine sand was prepared by composting it with a heavy application of chicken and cow manure followed by a long period of air-drying. It was then mixed with uncomposted Norfolk soil in various quantities and planted to millet to determine the proper mixture for optimum fertility. This mixture was then used in the experiment.

The millet used for transplanting was grown to approximately 10 inches in height in complete nutrient solution in sand culture. It was transplanted once to a two-compartment container prior to final use so that an untangled divided root system suitable for subsequent use would develop. No attempt was made to distribute the roots through the dry soil in the final transplanting to the experimental cultures. The greater mass of roots lay within an inch of the bottom of the compartment when the culture was complete.

Nitrogen-free nutrient solution was supplied daily to the quartz sand portion of each culture. Analyses of the plants and soil were made 4 weeks after transplanting.

RESULTS OF EXPERIMENT ON NITROGEN ABSORPTION

Data obtained are presented in Table 3. There was a marked difference in dry weight and percentage and total nitrogen between treatments 1 and 4. The dry weight of treatment 4 was 220% greater and the total nitrogen 516% greater than for treatment 1. The dry weight of plants in treatment 4 exceeded that of treatment 5, but

TABLE 3.—*Absorption of nitrogen by millet with root system transplanted one-half to fertile Norfolk loamy fine sand at the permanent wilting point and one-half to nitrogen-free nutrient solution in sand culture.*

Nitrogen source, three replicates	Millet top growth			Percentage soil moisture at harvest	
	Grams dry weight yield	N, %	Total N, mgm	Surface 2 inches	Center*
1, none; N-free sand culture only....	0.99	0.79	7.7	—	—
2, Norfolk soil at P.W.P. in open-top can†	1.87	0.85	15.7	0.73	0.94
3, Norfolk soil at P.W.P. in punched top can	1.25	0.86	10.8	0.99	1.55
4, Norfolk soil at P.W.P. in solid top can	3.16	1.50	47.4	1.74	2.12
5, Norfolk soil at optimum moisture..	2.61	3.30	85.9	—	—
L. S. D. at .05	0.95	0.27	13.7	0.24	0.36
L. S. D. at .01	1.38	0.39	20.1	0.41	0.60

*Upper extent of new root growth in treatment 4.
†The amount of water calculated to increase the soil moisture up to the permanent wilting point of 2.30 was added, but actual determination after mixing gave values of 1.98 to 2.24% soil moisture in the containers.

the percentage nitrogen was less than half and the total nitrogen 55% as great.

Treatments 2 and 3, with less protection against evaporation than treatment 4, did not show a significant response to the nitrogen in the dry soil. The final percentage soil moisture shows that the roots were not able to compete with evaporation as could the better protected roots in treatment 4. It is evident from the surface soil moisture percentage that evaporation also took place from treatment 4. Evaporation may also have been a factor in determining the final soil moisture at the top of the root zone.

The type of root growth which took place is shown by Fig. 3. Obviously, little or no growth took place under conditions of excessive evaporation from the soil. An interesting phenomenon was observed when the compartments of treatment 4 were opened. The top soil was loose and readily poured from the compartment down to the point at which the second soil sample was taken. At this point the soil fell free of a mass of root tips growing up into the surface soil in a uniformly level horizon.

The effect of nitrogen on the color of the plants was readily apparent in the different treatments. Plants of treatments 4 and 5 were almost normal in color, while those of treatments 1, 2, and 3 were very light in color. Another interesting phenomenon was observed in a plant of treatment 4 which had by accident had its root system

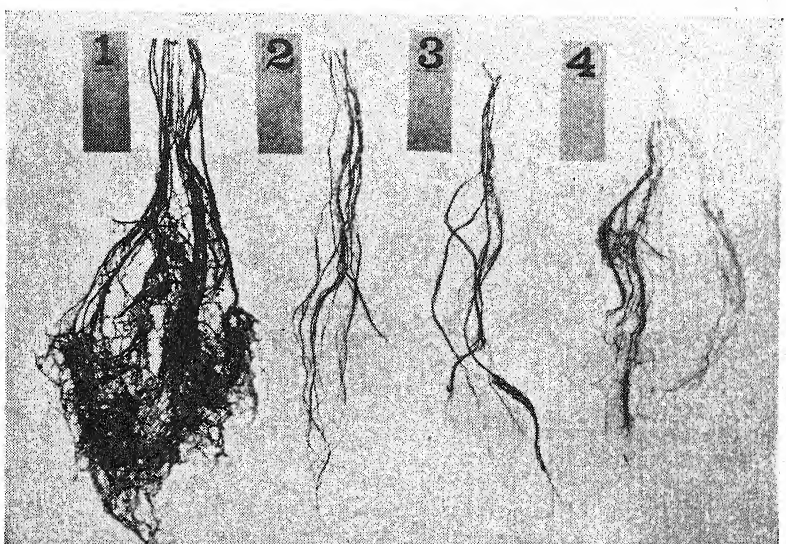

FIG. 3.—Secondary growth of roots of millet transplanted to a double compartment container with one portion of its roots in a nitrogen-free nutrient solution in sand and one portion in fertile Norfolk loamy fine sand initially at the wilting point. 1, Soil compartment sealed with solid lid; 2, soil compartment covered with lid punched with nail holes; 3, soil compartment without lid; 4, initial condition of roots when transplanted.

divided so that the axis through the new shoots tillering out from the sides of the crown was vertical to the common edge between the two compartments. A light green shoot grew on the left side of the plant toward the nitrogen-free sand compartment, while a dark green shoot grew on the side toward the dry fertile sand. This was an excellent example of the known difficulty that plants have of efficiently translocating certain nutrients across their crowns, and indicated the significance of the nitrogen being absorbed from the soil at the wilting point.

DESIGN OF EXPERIMENT FOR PHOSPHORUS AND POTASSIUM ABSORPTION

The experiment was carried out in the type of two-compartment culture described for the determination of the critical soil moisture. Each culture consisted of two plants with root systems divided over the edge of a rectangular tin container embedded in a 2-gallon glazed earthenware jar. The inner container was filled with fertile Clyde silt loam and the outer with quartz sand. Divided-root plants were developed in the same manner as described for the determination of the critical soil moisture. In addition, a temporary auxiliary plant was grown with its root system entirely in the inner compartment. It served rapidly to reduce the moisture in the inner compartment down to the permanent wilting point just prior to differentiation of the experiment. The complete wilting of this plant was used as a criterion that available moisture was exhausted. The experiment was differentiated 5 days later. All cultures were sealed with paraffin and beeswax just prior to reduction of the moisture to the wilting point by the auxiliary plants so as to prevent excessive desiccation of the top portion of the containers.

Treatments were as follows: 1, The auxiliary plant was removed and the seal left intact; 2, the auxiliary plant was left and the seal removed; 3, the roots (of the divided-root plant) leading to the inner compartment were cut and the plant allowed to continue growth with roots only in the outer compartment filled with sand, the soil being sampled for moisture content as a reference against the remaining treatments, 4, the seal and the auxiliary plant were removed and the soil kept at optimum moisture content for the remainder of the experiment.

Only tap water was used in the outer compartment until within 3 weeks of termination of the experiment at which time an application of calcium nitrate in solution was made to each of the outer compartments on order to augment the nitrogen being taken up from the soil.

The plants were harvested for analysis 6 weeks after differentiation of treatments. The soils of treatments 1 and 2 were sampled for moisture content.

RESULTS OF EXPERIMENT ON PHOSPHORUS AND POTASSIUM ABSORPTION

Data obtained are presented in Table 4. Those of treatments 1, 2, and 3 are the average of eight replicates and those of treatment 4 the average of four replicates. The soil moisture content was 8.87% at the time of differentiation according to the samples taken from treatment 3. It was 8.35% for treatment 1 and 5.58% for treatment 2 at termination of the experiment. The drop in treatment 1 below that indicated by treatment 3 was probably the result of evaporation around the seal, because the permanent wilting point as previously reported for Clyde silt loam was 8.91%. The percentage soil moisture in treatment 2 dropped to only 1.03 above the air-dry percentage.

The dry weight yield of treatment 1 (sealed) was 33% higher than that of treatment 2 (open). This difference is statistically significant at the 1% point. Both percentage and total of phosphorus and potas-

sium were higher for treatment 1. The total phosphorus was 70% higher, while the total potassium was 50% higher. It appears that these two elements were being assimilated in significant quantities from the soil maintained at approximately the wilting point.

TABLE 4.—*Absorption of phosphorus and potassium by corn with root system divided between fertile soil and permanently wet sand after depletion of available soil moisture by temporary auxiliary plants.*

Soil treatment*	Percentage soil moisture		Dry weight yield, grams	Phosphorus in plant		Potassium in plant	
	At differentiation	At harvest		%	Mgm total	%	Mgm total
1, sealed soil compartment	—	8.35	19.13	0.092	17.7	0.84	160
2, open soil compartment	—	5.58	14.42	0.072	10.4	0.73	107
3, roots cut from soil	8.87†	—	15.49	0.079	12.2	0.77	120
4, soil kept at optimum moisture	—	—	21.38	.199	42.7	1.59	340
L.S.D. at .05‡	—	—	2.36	0.0061	2.6	0.10	24
L.S.D. at .01‡	—	—	3.27	0.0085	3.6	0.14	33

*Data is average of eight replicates of treatments 1, 2, and 3; four replicates of treatment 4.
†Permanent wilting point of Clyde silt loam is 8.91% for corn.
‡Applies to first three treatments only.

The differences between treatments 2 and 3 are of interest in view of the fact that the only difference in treatment was the absence of roots in air-dry soil in treatment 3. Dry weight yield and percentage and total phosphorus and potassium are higher for treatment 3 than for treatment 2. It appears either that certain nutrients were withdrawn from the plant by the dry soil or that they were utilized by greater root growth in treatment 2 and, therefore, did not appear in the analysis.

Treatment 4 in which the soil was kept at optimum moisture did not produce significantly more dry weight yield than treatment 1, but it was much higher in both phosphorus and potassium. Data for phosphorus and potassium from this experiment, in general, substantiate that for nitrogen in the previous experiment. Certain elements apparently can be absorbed by plants with roots in soil depleted of available moisture but maintained approximately at the wilting point.

SUMMARY

The investigations were made with plants having root systems divided between soil under high moisture tension and soil or sand adequately supplied with moisture.

The critical soil moisture (that at equilibrium with the roots of a turgid plant) was 1.11 times the wilting point for Clyde silt loam and 1.12 times the wilting point for Plainfield sand. Corn grew roots into air-dry Plainfield sand and increased the moisture content to 2.3 times the initial level. Corn also grew roots into Clyde silt loam at

0.7 and 0.9 of the wilting point, and showed a net translocation of moisture into the dry soil.

Root growth into air-dry Plainfield sand to which a heavy application of fertilizer had been made, resulted in reduced plant growth and a higher percentage of potassium and nitrogen, but no change in phosphorus in the plant, as compared to a no-fertilizer treatment. There was an increase in both percentage and total potassium and nitrogen in plants which grew roots into dry Clyde silt loam of high fertility at below the wilting point, as compared to Plainfield sand of low fertility. There was very little, if any, increase in intake of phosphorus.

Total nitrogen assimilated by millet transplanted with one-half of its root system in a high-nitrogen soil at the wilting point was 55% of that assimilated from the same soil at optimum moisture, and over six times that present in the check growing only in nitrogen-free sand nutrient solution culture. The dry weight yield of corn receiving phosphorus and potassium and part of its nitrogen from soil at or slightly below the wilting point in a sealed container was 33% higher than for corn receiving these elements from the same soil in a container open to permit air-drying to take place. Potassium and phosphorus uptake were 50% and 70% higher, respectively, in the plant with part of its roots in a sealed container.

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The Clover Populations and Yields of a Kentucky Bluegrass Sod as Affected by Nitrogen Fertilization, Clipping Treatments, and Irrigation[1]

R. R. Robinson and V. G. Sprague[2]

PASTURE production throughout the northeastern United States is seriously limited by a deficiency of available nitrogen as well as by deficiencies of lime, phosphate, and potash. Inasmuch as nitrogen can be supplied most economically through the use of legumes, and since legumes are nutritious feed, a better understanding of the factors affecting the proportion of legumes in pastures is particularly important. At the present time *Trifolium repens* L. appears to be one of the most promising legumes on the better pasture soils in the region. Its principal weakness is the fluctuation in stand from year to year or even within the same season. The cause of this fluctuation has not been definitely determined but undoubtedly a number of factors are involved. Soil fertility, soil moisture, pasture management practices, competition from other plant species, winter injury, and perhaps disease appear to be among the most important factors affecting the stand of clover. The primary objectives of the present investigations were to determine the effects of nitrogen fertilization, soil moisture supply, and defoliation treatments on clover populations, total yields, and seasonal distribution of yields.

EXPERIMENTAL TREATMENTS AND PROCEDURE

The experiments reported in this paper were started in 1944 on a good sod of Kentucky bluegrass, *Poa pratensis* L., on Hagerstown silt loam. The area had been in Kentucky bluegrass since 1941 and had been clipped at intervals with a lawn mower. Very little clover was present at the time the experiment was started. In the early spring of 1944 the entire area was seeded uniformly with *Trifolium repens*. Since several clipping treatments were involved in the experiment, it seemed advisable to seed a mixture of several types of white clover. The mixture consisted of Ladino clover, 2 pounds; Kent white clover, 1 pound; Louisiana white clover, 1 pound; Polish white clover, ¾ pound; Wisconsin white clover, ½ pound; and Oregon white clover, ½ pound per acre.

The area was uniformly limed, and fertilizer was applied annually to all plots at the rate of 100 pounds P_2O_5 and 150 pounds K_2O per acre.

The experiment involved two soil moisture levels, two nitrogen levels, and four defoliation treatments in all possible combinations. Natural rainfall without supplemental water and natural rainfall plus irrigation at intervals and in amounts judged necessary for optimum growth provided the two levels of soil moisture.[3]

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[3]The writers wish to express their appreciation to Warren C. Huff of the Coke Oven Ammonia Research Bureau and to C. W. Skinner and Company, Bloomfield, N. J., for supplying the irrigation equipment used in this investigation.

In 1944, rainfall was excessive during May and early June whereas July and August were very dry (Table 1). In 1945, rainfall was much more favorable for growth during July and August than in 1944. The amounts of irrigation water used are shown in Table 1.

TABLE 1.—*Precipitation and irrigation data for the years 1944 and 1945 at State College, Pa.**

Month	1944			1945		
	Rainfall, inches	Irrigation, inches	Total, inches	Rainfall, inches	Irrigation, inches	Total, inches
April	4.05	—	4.1	4.38	—	4.4
May	7.83	—	7.8	6.09	—	6.1
June	5.70	—	5.7	3.19	1.3	4.5
July	2.08	2.4	4.5	2.63	1.7	4.3
August	1.52	4.7	6.2	3.00	3.0	6.0
September	2.60	1.0	3.6	6.50	1.2	7.7
Total	23.78	8.1	31.9	25.79	7.2	33.0

*Rainfall data were obtained from the reports of the Weather Bureau (4).

The nitrogen levels were no nitrogen fertilizer and a very high level of nitrogen fertilization (40 pounds per acre of nitrogen from ammonium nitrate in the early spring and repeated after each cutting except the last one in the fall). The total amount of nitrogen applied per year varied depending on the frequency of clipping. On the nonirrigated plots the range was from 200 to 320 pounds of nitrogen per acre in 1944 and from 280 to 360 pounds in 1945. On the irrigated plots the rates were from 320 to 440 in 1944 and from 360 to 440 in 1945. At the high nitrogen levels lime was added in amounts calculated to neutralize the excess acidity resulting from the use of the nitrogen fertilizer (11).[4]

Defoliation treatments were as follows: (a) Clipped to ½ inch when 4 inches high; (b) clipped to 1 inch when 4 to 5 inches high; (c) clipped to 2 inches when 5 inches high; (d) clipped to ½ inch when 3 inches high for the first two or three cuttings in the spring, and thereafter clipped to 1 inch when 4 to 5 inches high.

Because of practical considerations in applying irrigation water, the irrigated and the nonirrigated plots were located in separate blocks rather than being randomized. Within each of these blocks the treatments were arranged in a split-plot design with nitrogen levels as the main plots and clipping treatments as the sub-plots. Each sub-plots was 22 feet by 5 feet and all treatments were in quadruplicate.

Estimates of the percentage stand of clover were made prior to each clipping. In addition samples of herbage were taken from various plots at irregular intervals and separations were made to determine the percentage of bluegrass, clover, and weeds. Yields were obtained by harvesting a strip the width of the lawn mower through the length of the plot. The remainder of the plot was then clipped and the herbage removed.

EXPERIMENTAL RESULTS

The clover population was very small on all plots at the time the experiment was started, but following the uniform application of lime, phosphate, potash, and seed, clover increased rapidly under certain treatments. By midsummer of 1944 good stands of clover were obtained on the low nitrogen plots particularly under close clipping and irrigation (12). On the high nitrogen plots very little clover was present the first year except under a combination of close clipping and irrigation. The effects of the various treatments

[4]Figures in parenthesis refer to "Literature Cited", p. 116.

on the percentage stands of clover during 1945 are summarized in Table 2. The values given in the table are the average of several estimates during June, July, August, and September. These estimates, however, were consistently lower than the values obtained by actual separation of the grass, clover, and weeds in the herbage. Thus it can be concluded that the values in the table are conservative estimates of the clover content of the herbage.

TABLE 2.—*Clover populations of a Kentucky bluegrass sod during the summer of 1945 as affected by nitrogen fertilization, soil moisture, and clipping treatments.**

Clipping treatment	Estimated clover, %			
	Not irrigated		Irrigated	
	No N	High N†	No N	High N†
Cut to ½ in. when 4 in. high	57	28	52	48
Cut to 1 in. when 4–5 in. high	45	24	50	42
Cut to 2 in. when 5 in. high	36	1	33	32
Cut to ½ in. when 3 in. in early spring; then to 1 in. when 4–5 in.	54	20	55	60

*Figures are the average of several estimates during June, July, August, and September, 1945.
†The high nitrogen plots received 40 pounds per acre of nitrogen in the early spring and again after each cutting except the last one in the fall.

During 1945, without irrigation or nitrogen fertilizer, the more severe clipping treatments (½-inch cutting height) resulted in uniformly high percentages of clover, whereas the more lenient clipping treatment (2-inch cutting height) resulted in a denser sod of grass with considerably less clover. Regardless of the clipping treatment, the clover was predominantly of the large type. These results indicate that close clipping is not injurious to the large type clover provided ample time is allowed for recovery between cuttings. High rates of nitrogen fertilizer materially decreased the clover population and under the 2-inch height of clipping clover was practically eliminated. It should be noted, however, that under the more severe clipping treatments considerable amounts of clover were present even on the high nitrogen plots.

Of particular interest is the large amount of clover on the irrigated plots. With adequate moisture nitrogen fertilization had very little effect on the clover content of the herbage. At both high and low levels of nitrogen excellent stands of clover were maintained at all except the 2-inch height of clipping, and even under this treatment fairly good stands of clover were obtained. The very high clover population under high nitrogen and irrigation together with a severe clipping treatment is illustrated in Fig. 1. This plot received a total of 360 pounds per acre of nitrogen in nine applications in 1944 and 200 pounds in five applications in 1945 prior to the time the photograph was taken on July 16. At that time the plots of this treatment were estimated to have a 60% stand of clover. Botanical analyses showed

that 74% of the dry weight of the herbage consisted of clover. On plots with similar irrigation and clipping treatments but no nitrogen fertilizer, the herbage averaged 71% clover. Thus it is obvious that heavy nitrogen fertilization did not in itself eliminate clover from the Kentucky bluegrass sod.

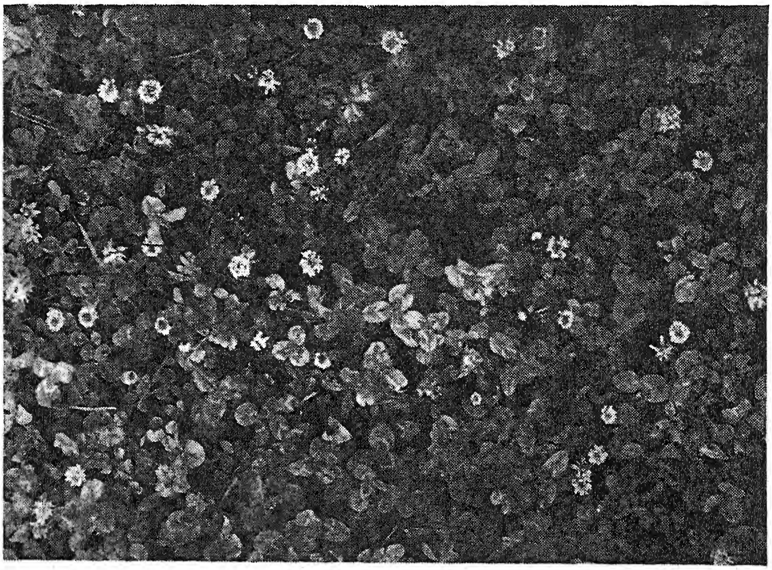

FIG. 1.—The botanical composition of plots that received high nitrogen fertilization and irrigation and were clipped to ½ inch when 3 inches high in the early spring and thereafter to 1 inch when 4 to 5 inches high. A total of 360 pounds per acre of nitrogen was applied in 1944 and 200 pounds in 1945 prior to July 16 when this photograph was taken.

The yields of herbage from the various treatments are summarized in Table 3 and the analysis of variance presented in Table 4. In 1944 nitrogen fertilization resulted in large increases in yield. Most of this increase was obtained in the spring months before clover became well established on the low nitrogen series. Since clover stands were generally high in 1945, excellent yields were obtained without nitrogen fertilization. Nevertheless, marked increases in yields were obtained from nitrogen fertilization, particularly on the plots clipped to a height of 2 inches. The value of F (13) for comparison of mean squares for clipping×nitrogen with mean square for error indicates that the greater response to nitrogen fertilization on the plots clipped to a height of 2 inches is statistically significant. Regardless of the level of nitrogen fertilization or of irrigation, however, the ½-inch clipping treatment gave the highest yields of dry matter and the 2-inch clipping treatment gave the lowest yields.

Irrigation greatly increased the yield during 1944 but produced surprisingly small increases in total yields for the 1945 season. The

TABLE 3.—*Yields of a bluegrass-clover mixture as affected by nitrogen fertilization, soil moisture, and clipping treatments.*

Clipping treatment	Yields of dry matter, pounds per acre			
	Not irrigated		Irrigated	
	No N	High N*	No N	High N*
1944				
Cut to ½ in. when 4 in. high	3,302	4,866	6,561	8,182
Cut to 1 in. when 4–5 in. high	2,570	4,462	5,758	7,482
Cut to 2 in. when 5 in. high	2,452	4,908	4,716	7,552
Cut to ½ in. when 3 in. in early spring; then to 1 in. when 4–5 in.	3,107	4,478	6,225	8,099
1945				
Cut to ½ in. when 4 in. high	7,048	8,146	7,505	8,541
Cut to 1 in. when 4–5 in. high	5,904	6,867	6,986	7,328
Cut to 2 in. when 5 in. high	4,083	6,326	5,289	6,579
Cut to ½ in. when 3 in. in early spring; then to 1 in. when 4–5 in.	6,303	7,526	6,511	7,415

*The high nitrogen plots received 40 pounds per acre of nitrogen in the early spring and again after each cutting except the last one in the fall.

seasonal distribution of yield during 1945, however, was greatly modified by irrigation. This is shown in Fig. 2 for high nitrogen plots clipped from 5 inches to 2 inches both with and without irrigation. As noted earlier this treatment without irrigation resulted in

TABLE 4.—*Analysis of variance of data summarized in Table 3.*

Source of variation	Degrees of freedom	Not irrigated		Irrigated		F required for	
		Mean square	F	Mean square	F	P = 0.05	P = 0.01
Nitrogen	1	41,019,221	32.7*	33,805,503	57.6**	10.1	34.1
Replications	3	4,855,066	3.9	1,627,907	2.8	9.3	29.5
Error (a)	3	1,255,827	—	586,646	—	—	—
Clipping	3	5,652,298	47.1**	7,512,564	88.2**	3.2	5.1
Nitrogen × clipping	3	1,006,792	8.4**	755,707	8.9**	3.2	5.1
Error (b)	18	120,039	—	85,204	—	—	—
Years	1	121,647,113	1258.2**	614,656	5.7*	4.3	8.0
Nitrogen × years	1	771,103	8.0**	5,034,414	46.3**	4.3	8.0
Clipping × years	3	2,981,470	30.8**	850,913	7.8**	3.1	4.9
Replications × years	3	706,111	7.3**	66,010	0.6	3.1	4.9
Nitrogen × clipping × years	3	125,615	1.3	185,871	1.7	3.1	4.9
Error (c)	21	96,681	—	108,715	—	—	—

*Exceeds 5% point.
**Exceeds 1% point.

practically pure Kentucky bluegrass during both years of the experiment. On the irrigated series the amounts of clover were negligible during 1944 and the early spring of 1945, but during midsummer and fall considerable amounts of clover were present. Irrigation greatly increased the yield during the dry part of the summer but in the early spring and again in late fall the nonirrigated plots produced much higher yields than the irrigated plots. Inasmuch as no irrigation water was applied in 1945 prior to June 24, it is obvious that the poor growth on the irrigated plots in the spring of 1945 was due to the effect of the irrigation during 1944. Similarly, the yield during the fall of 1945 when rainfall again became adequate indicates that irrigation during the summer adversely affected the grass.

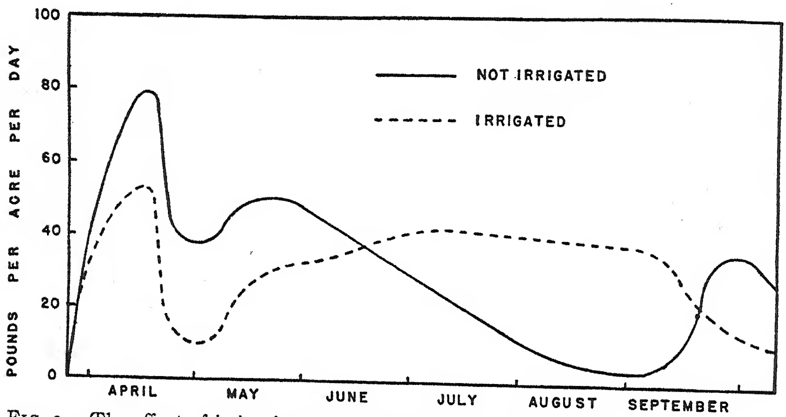

FIG. 2.—The effect of irrigation on the seasonal distribution of yields of dry herbage during 1945. All plots received high nitrogen fertilization (40 pounds per acre of nitrogen in the spring and repeated after each cutting) and the herbage was clipped to 2 inches when 5 inches high.

The sharp drop in the yield curves in late April and early May resulted from a prolonged period of cold weather following an unusually early spring. During this period of unfavorable weather, an epidemic of *Helminthosporium* leaf spot developed on the Kentucky bluegrass and was particularly severe on the high nitrogen plots of the irrigated series. Thus, during May, it would appear that *Helminthosporium* leaf spot as well as depletion of carbohydrate reserves contributed to the low yields of the irrigated plots.

DISCUSSION

The data presented in this paper show that under certain conditions excellent stands of white clover were obtained in a Kentucky bluegrass sod even with very high rates of nitrogen fertilization. These results are particularly significant because most experiments show that nitrogen fertilization decreases clover populations. This adverse effect on clover has been observed so consistently that the question often has been raised whether nitrogen fertilization was actually toxic to clover.

In the present experiments the data suggest that any changes in clover population resulting from nitrogen fertilization can be attributed to the indirect effects of the nitrogen. This is in agreement with the conclusions of Brown (3) and Blackman (1). When grass and clover are growing together they are competing for space, light, water, and plant nutrients. Any changes in these factors or of such factors as temperature, day length, management practices, and disease epidemics may be expected to result in changes in the proportion of grasses and clover in the mixture. It is well known, for example, that on very dry soils clovers are unable to compete with grasses. Mineral fertilizer ordinarily increases the proportion of clover in a pasture, whereas nitrogen fertilizer increases the proportion of grass. Because of the factor of plant competition, however, it would appear that any conclusions regarding the relative fertilizer requirements of grasses and legumes based on the growth of these species in association would be subject to serious errors. Undoubtedly an important factor in the rapid increase in clover content of a poor sod following top-dressing with lime, phosphate, and potash is that the predominant grasses on poor soils are poor competitors. Even when Kentucky bluegrass is present in considerable amounts the growth is limited by a deficiency of available nitrogen. Therefore the grass offers little competition to the clover for the first year or two. Later as the grass benefits from the nitrogen fixed by the clover the sod becomes thicker and the clover population usually declines materially even though the fertilizer applications are repeated.

Unpublished data obtained by the writers show that regardless of fertilizer levels Kentucky bluegrass grown under long day length in the greenhouse produces elongated leaves and a much more open type of growth than when grown under a short day. Sprague (14) found that in young seedlings the temperature for optimum growth was higher for Ladino clover than for Kentucky bluegrass. These factors may offer a partial explanation for the observation during the present investigation that with adequate soil moisture white clover appears better able to compete with Kentucky bluegrass during midsummer than during early spring or late fall.

Management practices, particularly as they affect the carbohydrate reserves of the various plant species, may greatly modify the grass-clover ratio. The importance of carbohydrate reserves in plants is perhaps more generally appreciated in alfalfa than in other plant species. Frequent clipping of alfalfa-grass mixtures or of pure alfalfa depletes the carbohydrates reserves of the roots of the legume and it is soon eliminated. It has also been shown that severe clipping, particularly with high nitrogen fertilization, depletes the food reserves of Kentucky bluegrass. This work is reviewed in a recent publication by Brown (5). Of particular significance is the work of Sullivan and Sprague (15) which shows that in ryegrass most of the carbohydrate reserves are stored in the stubble rather than in the roots. If Kentucky bluegrass also stores carbohydrate reserves in the stubble, it is obvious that part of these reserves would be removed by close clipping.

It appears from the data presented in Fig. 2 that forcing Kentucky bluegrass during the summer by means of irrigation even with lenient clipping treatments (5 inches to 2 inches) lowers the carbohydrate reserves. Since no irrigation water was applied in 1945 prior to June 24, the poorer growth of Kentucky bluegrass on the irrigated plots in the early spring of 1945 is attributed to the effects of irrigation during the preceding summer (the amounts of clover on these plots during 1944 and early 1945 were negligible). In the fall of 1945 the adverse effects of irrigation during the summer were again evident. This effect of irrigation on subsequent growth is in agreement with the work of Brown (5) who reported that irrigation during the hot summer months resulted in losses of carbohydrates from rhizomes of Kentucky bluegrass.

The question may well be raised, however, whether the level of carbohydrate reserves that is best for the grass is also best for the pasture. One of the major problems in pastures is the maintenance of legumes. If the pasture is managed to maintain a dense sod of bluegrass, clover will be largely crowded out. More than 30 years ago Carrier and Oakley (6) concluded that more bluegrass pastures are injured by undergrazing than by overgrazing. More recently Johnstone-Wallace (9) and others recommended early spring grazing to weaken the grass and thereby increase the stand of clover. Dodd (7) concluded that control of grass growth is necessary to the maintenance of white clover. In Connecticut, Brown (2) found that when grazing was started May 5 total production was more than twice as great as where grazing was delayed until June 10. The data obtained in the present investigation substantiate these earlier results. In all cases the more severe clipping treatments resulted in increased percentages of clover and in higher yields. Where moisture was adequate, close clipping gave excellent stands of clover even on the high nitrogen plots. As noted earlier, however, the epidemic of *Helminthosporium* leaf spot later in the spring may have been an additional factor contributing to the high clover population under high nitrogen and irrigation.

The importance of clipping treatments that weaken the grass was particularly apparent on the high nitrogen plots of the nonirrigated series. Except where the plots were closely clipped the clover was practically eliminated. On the closely clipped plots considerable amounts of clover were present.

The question may also be raised as to the effect of severe clipping treatments on the carbohydrate reserves of white clover. It would appear, however, that clover is better able to withstand periodic close clipping than is Kentucky bluegrass provided adequate time is allowed for recovery between clipping dates. Thus, Brown (3) found that clipping to 1 inch when the herbage reached a height of 2 inches resulted in less clover than was obtained where the herbage was allowed to grow to a height of 4 or 5 inches before clipping. During a favorable growing season, Mott (10) found that in a Ladino clover-Kentucky bluegrass mixture the yield of legumes on plots clipped to ½ inch when 4 to 6 inches high was more than four times as great as on plots clipped to ½ inch every week. In the

present investigations the grass was almost crowded out by the dense stand of clover on certain of the closely clipped plots during the favorable season of 1945. Thus, it appears that during "clover years" it sometimes may be desirable to manage the pasture to favor the grass rather than the clover.

It must be recognized, however, that regulating the carbohydrate reserves of Kentucky bluegrass in order to encourage clover does not solve all the problems of pasture management. In fact such a program would not be advisable in areas subject to frequent periods of drought because of the uncertainties of maintaining clover. Even under the best management practices clover may be lost due to winter injury, severe drought, or some other cause. The farmer would then have neither clover nor good grass. Moreover weeds might also become a serious problem. This is well shown by the work of Graber (8). Investigations over a period of years are necessary to determine the proportion of grasses and legumes that will give the highest yields without unduly increasing the hazards associated with loss of clover.

SUMMARY AND CONCLUSIONS

Clover populations and yields of herbage as affected by two levels of soil moisture, two levels of nitrogen fertilization, and four clipping treatments in all possible combinations were determined on a Kentucky bluegrass sod during 1944 and 1945. The moisture levels were natural rainfall with and without irrigation; the nitrogen levels were no nitrogen fertilization and a very high level of nitrogen fertilization (40 pounds of nitrogen per acre in the early spring and repeated after each clipping); and the clipping treatments included (a) clipping to ½ inch when the herbage reached a height of 4 inches, (b) clipping to 1 inch when 4 to 5 inches high, (c) clipping to 2 inches when 5 inches high, and (d) clipping to ½ inch when 3 inches high in the early spring and thereafter clipping to 1 inch when 4 to 5 inches high. All plots were limed and well fertilized with phosphate and potash.

On plots without nitrogen fertilization or irrigation the closer clipping treatments (½ inch and 1 inch) resulted in excellent stands of clover. Clipping to a height of 2 inches produced a more dense sod of grass with considerably less clover.

High rates of nitrogen fertilization, without irrigation, greatly decreased the stand of clover and on the plots clipped to 2 inches clover was practically eliminated. With the more severe clipping treatments considerable amounts of clover were maintained even with heavy nitrogen fertilization.

On the irrigated plots, clipping to ½ inch or 1 inch resulted in excellent stands of clover even on plots that received as much as 360 pounds of nitrogen per acre per year. Fairly good stands of clover were maintained at the 2-inch height of clipping.

The highest yields of dry matter were obtained on the plots clipped to ½ inch, whereas the lowest yields were obtained on plots clipped to 2 inches.

It is concluded that clover populations are determined by the ability of the clover to compete with grass for space, light, moisture,

and nutrients. Changes in these factors or of such factors as management practices, winter injury, severe drought, or disease epidemics may greatly change the botanical composition of the pasture. Management practices, particularly as they affect the carbohydrate reserves of the grass, are especially important. It is emphasized that the level of carbohydrate reserves which is best for the grass may not be the best for the pasture. In the present experiment close clipping with ample time for recovery between clipping dates was very effective in maintaining clover.

The results obtained in these experiments indicate the need for studies under grazing conditions to determine the possibilities of increasing the clover content and thereby the yields of pastures.

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Sweet Corn Not an Important Indian Food Plant in the Pre-Columbian Period[1]

A. T. Erwin[2]

SWEET corn, Zea Mays, L. var. rugost, Bonaf., was not extensively used as an Indian food plant in the United States in pre-Columbian times, concluded the writer in a paper (2)[3] dealing with this subject. George F. Carter, assistant professor of Geography, Johns Hopkins University, in an interesting volume entitled "Plant Geography and Culture History in the American Southwest," takes issue with this opinion and suggests that the writer has not given sufficient consideration to the literature of the upper Missouri and also to the literature of northeastern United States, rejected by the writer as inadequate.

Will and Hyde (7), referred to by Carter, list 104 varieties of corn collected from 18 tribes. Ninety-nine of the varieties are designated as field corn and five as sweet corn. In other words, 95% of the list is field corn and 5% sweet corn. Sweet corn is listed from 6 of the 18 tribes. Two-thirds of the tribes grew no sweet corn.

The fact should also be noted that their sweet corn was not used for roasting ears, according to Will and Hyde, but was crushed and made into balls which suggests its use as a confection rather than a food product. It should not be inferred that the Indians did not relish roasting ears, for the green corn season was "one of great rejoicing and feasting." Granted that the list of varieties grown by the Indians in 1915 is representative of that time, the question still remains as to conditions in the pre-Columbian period. A century had elapsed since the white man first visited the upper Missouri and the habits of the Indian have been influenced in many ways by the white man.

The writer does not question the accuracy of Will and Hyde's survey, but the statement of the Indians as to the antiquity of these varieties requires verification from other sources. In the absence of a calendar and a written record, too much should not be taken for granted. During the interval referred to, the Indians' habits were modified in many ways. The so-called Indian pony, an animal some of the tribes claim they had "always," despite facts of history to the contrary, is a good example.

However, accepting the evidence of Will and Hyde at full value as representing the pre-Columbian period, the evidence is still unimpressive. The fact should be borne in mind that in the pre-Columbian period, the four-footed beast of burden did not exist on this continent, hence corn was grown exclusively for human consumption.

"The certainty as to the origin of maize will come rather from archeological discoveries," noted DeCandolle.

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[1]Journal Paper No. J-1392 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project 293. Received for publication September 13, 1946.

[2]Professor.

[3]Figures in parenthesis refer to "Literature Cited", p. 121.

Will and Hyde (7) found cobs and some kernels of field corn in a Mandan site near Bismarck, N. D., but no sweet corn. Important archeological evidence bearing upon the early history of maize in the central Mississippi Valley, the heart of the Corn Belt, is to be found in the Ozark Bluffs, known as the Bluff-Dweller culture, and also the King Mounds in Kentucky. Flour, dent, and flint corns are well represented in the Bluffs-Dweller collection, but no sweet corn. Sweet corn is also absent from the King Mounds collection.

Papago sweet corn mentioned by Freeman of the Arizone Experiment Station has been referred to as historic sweet corn. Dr. R. H. Forbes, who accompanied Freeman on a trip at the time this corn was discovered, reports that the Papago sweet corn was grown adjacent to a field of Indian corn and was regarded by him and Freeman as the result of a cross with imported sweet corn.

Carter refers to Jalisco as a centre of sweet corn culture in Mexico. Kelly, who first reported the discovery of Jalisco sweet corn, says that it is not a food commodity, and Anderson[4] who has conducted extensive maize studies in this region reports that "Sweet corn is not grown for green corn. So far as is known, it is always grown for its sugary content and is used either in primitive sweet drinks or in primitive kinds of candy. Only at fiesta time, if ever, does it come into city markets. In little villages in Jalisco, it is quite common and is very often grown by some old widow lady who makes a specialty of preparing these old-fashioned sweetmeats and selling them at fiestas or from a little stand in front of her house. It is never thought of as being of any use as a table corn and one is nearly always told that it is too stocky for that purpose and will gum up the teeth."

The fact that sweet corn mutations occurred in pre-Columbian times, the writer has never questioned. In fact, the only ear of sweet corn which has come to light in the archeological collections of the United States so far was described by the writer (3). As to its existence in Mexico, the author stated in the paper referred to by Carter, "It can scarcely be said that this plant does not exist in some of the innumerable valleys with such widely varying soil and climate. Certainly at the seat of a civilization, based upon a maize culture, sweet corn mutations may even occur more frequently than elsewhere." The point is that it was not sufficiently prized to warrant its extensive propagation as a food plant.

Concerning the unstable character of Mexican sweet corn, Anderson (1) makes this comment, "Sweet corn is a single gene difference. In the case of Mexican sweet corn, this character becomes still less reliable, since Mexican dents carry suppressors which may prevent the sweet character from showing even when it has been inherited."

Reports from Colombia indicate that it is not a food plant in that region. In Guatemala, where we find remarkable variants of the maize plant, Dr. I. E. Melhus, who has spent considerable time in that region during the past two years, states that to date he has not found any sweet corn in that country. Apparently the Indian has his own ideas about flavor and they do not necessarily coincide with those of the white man.

[4]Letter to the author August 17, 1946.

The author is indebted to Dr. Hugh C. Cutler for the following note regarding sweet corn in Bolivia: "Sweet corn was found only in the altitudes above about 1,500 meters, and in the lower 500 meters and upper 500 meters I found only occasional sweet grains on otherwise flint or flour ears. In the valleys about 2,500 feet in Peru and Bolivia, sweet corn is most developed, although it never is cultivated to any large extent and only occasionally appears in the market, in the form of dried ears. Sweet corn is only eaten as parched dry grains or used in the fabrication of an especially esteemed potent *chicha*, reputed to have more alcohol than the usual type. This chicha and parched corn are only used by the richer people of the types who still use these products. Sweet corn is never eaten green on the cob in Bolivia. The corn has very little flavor and is watery. I greatly preferred ears of the large-grained white or yellow Cuzco flour type for eating green and could see little reason for eating the sweet corn.

"In the state of Sao Paulo, Brazil, Dr. Brieger at Piracicaba and Dr. Krug at Campinas, have developed varieties of sweet corn on Brazilian plant types which have most of the advantages of Brazilian corn but have the flavor and texture of Golden Bantam. These have met with little favor, however, except among the people who have been able to learn how to cook sweet corn properly. The ordinary yellow flint which is used for green ears is picked after it passes the milk stage and then stewed in hot water (seldom boiling) for as much as an hour, although sometimes it is taken out after half this time, or left for longer."

In passing, the fact should be noted that flavor is not a taxonomic character. The term "sweet" has numerous applications and even, in the case of corn, it does not necessarily refer to Zea Mays var. *rugosa*, as has been taken for granted by some writers. In the south, for example, many a sale of field corn in the roasting ear stage has been made as being "fresh, tender, and sweet." Likewise, Will and Hyde report that field corn picked in the milk stage was invariably called sweet corn by the early travelers of the upper Missouri.

The writer now turns to the evidence presented in the literature of northeastern United States, which was treated as unacceptable. There are two important publications relating to this region. The one is by Sturtevant (4), and the other by Parker (6).

Sturtevant quoted a statement from the *New England Farmer* to the effect that Bagnell, a member of Sullivan's expedition against the Iroquois, collected sweet corn seed from this tribe. The *New England Farmer* in turn quoted from an anonymous article in a local newspaper, *The Old Colonial*, published at Plymouth, Mass. The anonymous author, who styles himself "Plymothens," based his statement upon a legend that somebody told grandfather some four decades before that Bagnell secured some sweet corn seed from the Iroquois Indians. However, there is extant a detailed diary of Sullivan's expedition. Sullivan mentions finding quantities of field corn, beans, pumpkins, etc., but not a word is mentioned about sweet corn.

The second important reference is that of Parker. He lists sweet corn as an Indian food plant of the Iroquois and cites as his authority

the "Journal of Captain Richard Bagnall." In answer to a letter requesting information as to the repository of Bagnall's journal, Parker referred us to the oft quoted reference of Sturtevant.

In a further effort to locate the "Bagnall Journal", the author wrote the New York State Library for information. A letter from Edna L. Jacobson, Head, Manuscript and History Section, reads as follows:

"I find no mention of a journal of Richard Bagnall in the various publications of journals or lists of journals relating to Sullivan's expedition or in Henriette M. Forbes' New England Diaries, 1602–1800, published in 1923." From the evidence presented so far, Bagnall's diary, like the Plymothens article, appears to be nothing more than a myth.

However, even a legend is not to be ignored, as it may afford a valuable clue to more substantial evidence. In this case, such evidence appears to be lacking. In fact, early literature clearly points to a contrary conclusion.

In Thomas Jefferson's Garden Book, he notes for the year 1774, "Indian corn[5] comes to the table." Then in 1810, 36 years later, he mentions "sweet or shriveled corn" for the first time. The fact may also be noted, that he names the varieties of field corn planted in his garden, but in the case of sweet corn it would appear to be something new which does not yet have a varietal name.

Neither does sweet corn appear to have been known at this early date in the seed trade. Jefferson mentions dealings with a seedsman, Bernard McMahon, but the American Gardeners' Calendar (1806) written by McMahon, and the first important book on American gardening, lists no sweet corn. In fact, the second edition published in 1818 lists field corn "Indian corn for boiling."

Briefly stated, the archeological evidence, the most important criteria available, points to but a single ear of sweet corn, discovered by Earl H. Morris, and described by the writer (3), and a single grain discovered in the southwest by Volney Jones. From such evidence, representing the numerous Indian tribes of the United States, estimated by Mooney (5) at 849,000 population, covering the wide extent of the United States, the writer is unable to give sweet corn a significant role in the diet of these people in pre-Columbian times.

There is a very important practical reason why the Indians of pre-Columbian times did not rate sweet corn as an important food plant. The sweet corn plant is a weakling compared to field corn and, as a crop, it is illy adapted to the rigors of an Indian agriculture. It is more sensitive to temperature requirements at planting time and hence is planted later than field corn, otherwise the seed is liable to decay. At roasting ear stage, it is more subject to depredations of the corn ear worm and mold which follows in the wake of such injury. At harvest time, the ears are more difficult to cure, consequently the sweet corn ears are a more ready host to pathogens. The shriveled kernel is due to a shortage of endosperm, the factor which makes a plump kernel of field corn.

[5]The term "Indian corn" has been applied to field corn in many sections of the east since colonial times.

In Carter's concluding paragraph he states, "It is confidently expected that the Northeast will prove the source of our commercial flint and dent types of sweet corn." The author entirely agrees with this conclusion, provided that it carries the further stipulation that its commercial introduction there was due to the white man and not the Indian. The early literature clearly records the fact that the first varieties of sweet corn came from northeastern United States.

From the evidence so far submitted, the author sees no reason to deviate from his previous conclusion that, "sweet corn was not an important Indian food plant in the United States in the pre-Columbian period." In fact, judging from the evidence so far presented, the same statement would also seem to apply to several of the Latin American countries.

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Variations in Length, Strength, and Fineness of Cotton Fibers from Bolls of Known Flowering Dates, Locks, and Nodes[1]

N. I. HANCOCK[2]

PLANT breeders, and other workers on cotton, are confronted with variations in length, strength, and fineness of lint. These variations are due largely to the long fruiting period of the cotton plant, which extends from 6 to 10 weeks throughout most of the Cotton Belt. The fruiting period of cotton is considerably longer than that of corn, small grains, or other crop plants. Environment, therefore, has ample opportunity to affect differentially the cotton inside the bolls.

The long fruiting period developing through varying seasonal conditions, moreover, results in the complex structural growth of the cotton plant. Usually, there are from 8 to 16 fruiting limbs, with from 1 to 6 fruiting nodes on each limb, and 5-lock, 4-lock, and less-than-4-lock bolls growing from the fruiting nodes. Many workers have considered the particular structural growth itself as an expression almost wholly of environmental effects.

It is the purpose of this paper to give measurements of length, strength, and fineness of cotton contained by the bolls in relation to their plant structure, and to make suggestions concerning their sampling which may explain some of the variations.

MATERIAL AND METHODS

The cotton for these studies was harvested in 1932 from bolls of three varieties, Stoneville 2, Trice 90-1, and Wilds 1. Bolls of these varieties harvested in 1933 are at hand, but measurements are not complete. Stoneville 2 and Trice 90-1 represent 1-inch staple cottons of relatively the same maturity but of different boll lock numbers. Wilds 1 is a long-staple cotton of later maturity. Commercial breeders' seed of Stoneville 2 and Wilds 1 was used; seed of Trice 90-1 came from an isolated block of this station and is an S_3 inbred selection from the Trice variety.

These varieties were grown at the West Tennessee Experiment Station, Jackson, and at the main Station at Knoxville, in the East Tennessee Valley, thus, assuring wide differences in soil and climate.

Three-row plots, 60 feet long, of each variety were repeated seven times at Jackson and five times at Knoxville. Bolls were harvested from five plants in the middle row of each plot at Jackson and from seven plants at Knoxville. Hence, each variety is represented by eight groups of five plants each at Jackson and by six groups of seven plants each at Knoxville.

Every flower on the 120 plants at Jackson and the 126 plants at Knoxville was tagged. White tags were used on the first node, red tags on the second, yellow on the third, and green on fourth. Nodes beyond the fourth were marked with green tags. The flowering date was written on the tag at time of placement, and boll-opening date at time all sutures at tip end of boll were cracked. Bolls were harvested when cotton had the fluffy appearance of normal picking time.

[1]Contribution from the Department of Agronomy, Tennessee Agricultural Experiment Station, Knoxville, Tenn. Received for publication May 7, 1946.

[2]Agronomist. The author is grateful for the suggestions of Dr. K. L. Hertel and the use of instruments of the physics laboratory which made possible these studies. Also thanks are given to Misses Elizabeth Cotter, Louise McCamy, Reba Lawson, and Ruth Carl for the data on measurements and their listing for this study.

Each boll was hand-ginned and data were recorded as to the identity of plant and node, number of seeds, number of motes, weight of lint, weight of seed, and weight of motes, as well as measurements of length, strength, and fineness. Fig. 1 shows the method of listing data on the card which represents a single boll. This study is a brief summary of data for node and lock number, length, strength, and fineness on 1,012 bolls of the three varieties at Jackson and 1,131 bolls at Knoxville.

The fibrograph, which measures length (upper half mean length in these tables); the arealometer, which measures fineness; and the Pressley fiber-strength tester were described and literature pertaining to them given in a previous paper by the author (3).[3] It was shown that these instruments offer rapid and accurate methods for studies and tests of the plant breeder and the agronomist, and give more accurate measurements with less bias than commercial classing. They are now being used to some extent by the spinner.

RESULTS

It is generally understood that measurements of all individuals of a given population cannot be obtained, so that random samples are drawn as the best estimates of such a population. In this study, however, the population means of all the bolls of 40 plants of each variety at Jackson and 42 at Knoxville are known. In Table 1, the length, 31.7; strength, 6.59; and fineness, 2.53, represent the mean values of 404 bolls of Stoneville 2 at Jackson, and 31.8, 6.11, and 2.77, respectively, of 528 bolls at Knoxville; the other two varieties are recorded in the same manner. These averages may be called the true, or most nearly exact, mean values which the variety possesses under existing conditions. All other methods of sampling or grouping should give mean values which differ very little from these true ones. For example, if all the cotton from the 404 bolls of Stoneville 2 were properly mixed and random samples drawn, very few of these samples should differ more than 1.5 32nd inch (twice S.D.) above or below the true value of 31.7. But actually no machine gives this kind of mix in cotton. Besides, it would be impractical for the breeder or the agronomist to harvest all the cotton of a progeny row or plot for the purpose of taking a sample.

In this study, however, the boll measurements can be grouped in various ways to simulate the mix. In Tables 2 and 3, the mean values are shown for the eight plots or groups of five plants each at Jackson

S	1	J	32
VARIETY	PLANT NO.	STATION	YEAR

11	BOLL No.	NUMBER OF LOCKS	4
219	FLOWER DATE	NUMBER OF SEEDS	25
276	MATURITY DATE	NUMBER OF MOTES	5
4	NODE No.	WEIGHT OF LINT	1.28g
GINNING DATE	11/5/35	WEIGHT OF SEEDS	2.37
GINNER	Lovell	WEIGHT OF MOTES	.04

LENGTH 32.6 STRENGTH 6.62 FINENESS 2.23

FIG. 1.—Method of listing data on a card which represents a single boll.

[3]Figures in parenthesis refer to "Literature Cited", p. 134.

TABLE 1.—*Mean length, strength, and fineness of lint of Stoneville 2, Trice 90-1, and Wilds 1 at Jackson and Knoxville, 1932, as given by means of bolls and means of groups in Tables 2 and 3.*

Variety	Jackson				Knoxville			
	Number	L,* 32nds in.	S,* lbs., mg.	F,* cm²., mg.	Number	L,* 32nds, in.	S,* lbs., mg.	F,* cm²., mg.
Stoneville 2:								
Bolls....	404	31.7	6.59	2.53	528	31.8	6.11	2.77
Groups..	8	31.5	6.62	2.51	6	32.1	6.08	2.82
Trice 90–1:								
Bolls....	341	30.3	6.68	2.76	471	30.7	6.47	2.94
Groups..	8	31.0	6.60	2.82	6	31.2	6.45	2.95
Wilds 1:								
Bolls....	267	37.5	6.98	3.52	314	35.5	6.54	3.66
Groups..	8	37.3	6.92	3.56	6	35.6	6.50	3.67

*L = Upper half mean length; S = Strength; F = Fineness.

and six plots or groups of seven plants each at Knoxville. In Table 1 the means of these groups are compared with the true means of the bolls. It is obvious that the differences would be insignificant. When individual groups in Tables 2 and 3 are compared with true means, it is observed that at Jackson only one difference of the 24 falls outside the range of 1.33 32nds inch for length, while no groups varied significantly outside 0.55 for strength and 0.34 for fineness. At Knoxville 1 out of the 18 fell outside the range 1.4 in length, while none of the groups varied significantly from their true means in strength and fineness.

TABLE 2.—*Length, strength, and fineness of eight groups, five plants per group, representing Stoneville 2, Trice 90-1, and Wilds 1 at Jackson, 1932.*

Variety	Groups							
	1	2	3	4	5	6	7	8
	Length, 32nds inch							
Stoneville 2..........	32.5	31.7	30.5	32.5	32.0	31.4	30.7	31.4
Trice 90–1..........	29.6	31.5	30.8	31.0	32.3	30.6	30.2	32.3
Wilds 1.............	35.6	37.0	37.1	37.8	37.4	37.2	38.0	38.2
	Strength, lbs./mg.							
Stoneville 2..........	6.61	6.66	6.46	6.70	6.66	6.45	6.84	6.61
Trice 90–1..........	6.31	6.69	6.60	6.54	6.89	6.72	6.58	6.50
Wilds 1.............	6.81	6.75	6.88	6.98	6.93	6.78	7.12	7.11
	Fineness, cm²/mg.							
Stoneville 2..........	2.27	2.47	2.29	2.48	2.43	2.68	2.60	2.82
Trice 90–1..........	3.00	2.91	3.05	2.90	2.94	2.67	2.38	2.73
Wilds 1.............	3.56	3.24	3.39	3.90	3.29	3.64	3.54	3.87

TABLE 3.—*Length, strength, and fineness of six groups, five plants per group, representing Stoneville 2, Trice 90-1, and Wilds 1 at Knoxville, 1932.*

Variety	Groups					
	1	2	3	4	5	6
	Length, 32nds inch					
Stoneville 2	30.7	31.7	32.2	32.5	32.1	33.1
Trice 90-1	32.4	31.0	29.8	31.5	31.8	30.8
Wilds 1	35.6	35.2	35.4	35.0	35.3	36.9
	Strength, lbs./mg.					
Stoneville 2	5.95	6.17	6.07	6.10	5.96	6.23
Trice 90-1	6.24	6.70	6.17	6.54	6.56	6.50
Wilds 1	6.83	6.24	6.18	6.43	6.63	6.70
	Fineness, cm^2/mg.					
Stoneville 2	2.69	2.85	2.74	2.89	2.91	2.86
Trice 90-1	3.02	2.79	3.07	2.98	2.96	2.87
Wilds 1	3.61	3.77	3.62	3.65	3.64	3.73

There is not space to report the variations in all three characters of these varieties when bolls are grouped by plants or bolls upon a plant. So that only length for Stoneville 2 at Jackson is shown in Tables 4 and 5. More variation would be expected as groups are broken down by plants and bolls on a plant. In Table 4 the standard deviation now is 1.89 32nds of an inch for the mean lengths by plants and in Table 5 the 10 bolls of plant 1 in group 1 have a standard deviation of 1.93. It is seen in Table 5, moreover, that all plants do not have this high degree of variation. The agronomist who conducts variety or fertilizer tests may take groups of plants, but the breeder must resort to single plants as the units of selection and is confronted with the situation found in Table 5. He cannot pick all the bolls from individual plant selections. Under a method of this kind it would be necessary to designate and to make at least two pickings of several thousand plants. Is there a way to eliminate extreme values and be reasonably sure that the few bolls picked represent the plant?

TABLE 4.—*Length of cotton in 32nds of an inch for five plants of each group, of the eight groups, representing Stoneville 2 at Jackson, 1932.**

Plants	Groups							
	1	2	3	4	5	6	7	8
1	34.2	30.4	32.1	32.5	32.0	30.0	29.5	32.5
2	30.7	31.0	26.5	32.3	32.1	30.7	29.9	31.7
3	31.4	30.6	29.9	29.6	33.3	29.2	28.5	32.0
4	33.3	32.3	31.7	31.6	30.4	33.3	33.6	29.9
5	32.8	34.4	32.2	36.3	32.0	34.0	32.0	31.1

*Upper half mean length.

TABLE 5.—*Length of cotton in 32nds of an inch from bolls in their order of maturity, representing each of five plants in first group of Stoneville 2, Jackson, 1932.*

Plants									
1		2		3		4		5	
Bolls	Length*	Bolls	Length	Bolls	Length	Bolls	Length	Bolls	Length
1	34.8	1	30.1	1	31.3	1	32.1	1	32.3
2	33.3	2	29.0	2	32.3	2	33.4	2	34.2
3	31.6	3	31.0	3	30.2	3	32.7	3	33.1
4	34.2	4	32.3	4	31.1	4	34.9	4	34.7
5	36.3	5	31.2	5	31.3	5	33.8	5	34.1
6	36.0	6	31.7	6	32.0	6	34.4	6	31.4
7	34.8	7	29.0	7	31.8	7	31.6	7	30.2
8	37.0	–	—	8	31.0	8	31.0	8	32.3
9	31.5	–	—	–	—	–	—	–	—
10	32.6	–	—	–	—	–	—	–	—
S.D.	1.93		1.29		0.66		1.37		1.53

*Upper half mean length.

In the first place, suspicion has long existed that 4- and 5-lock bolls of the variety differ significantly in lint characters, such as length, strength, and fineness. In the regional cotton variety tests there was the requirement that 4- and 5-lock boll samples be kept separate. It is seen in Table 6 that Stoneville 2 has a higher percentage of 5-lock than 4-lock bolls at both Jackson and Knoxville, whereas Trice 90-1 has a higher percentage of 4-lock than 5-lock bolls. Wilds has a considerably higher percentage of 4-lock than 5-lock bolls, approximating the ratio 70 to 30.

TABLE 6.—*Percentage of 4-lock and 5-lock bolls obtained from Stoneville 2, Trice 90-1, and Wilds 1 at Jackson and Knoxville, 1932.*

Variety	Jackson		Knoxville	
	4-lock	5-lock	4-lock	5-lock
Stoneville 2	41.2	58.8	31.0	69.0
Trice 90–1	62.3	37.7	60.1	39.9
Wilds 1	70.0	30.0	76.4	23.6

The data in Table 7 show no significant differences between 4- and 5-lock bolls in length, strength, and fineness. Pope and Ware (6) found no significant differences in length, chroma, and brilliance between the 4- and 5-lock boll samples in the regional test. In their recent publication (7) such small differences were obtained between 4- and 5-lock bolls that only 4-lock bolls are reported for fiber properties. In this study large differences would surely have been obtained from the bolls of Wilds 1 where there is such disparity between the number of 4- and 5-lock bolls at both Jackson and Knoxville. It is observed, however, that differences between 4- and 5-lock bolls of Wilds 1 are even less than those in the other two varieties.

TABLE 7.—*A comparison of 4- and 5-lock bolls in length, strength, and fineness of the varieties Stoneville 2, Trice 90-1, and Wilds 1 at Jackson and Knoxville, 1932.*

Variety	Jackson		Knoxville	
	4-lock	5-lock	4-lock	5-lock
	Length, 32nds inch			
Stoneville 2	31.7	31.7	31.8	32.0
Trice 90-1	30.5	30.1	31.1	30.8
Wilds 1	37.6	37.5	35.5	35.8
	Strength, lbs./mg.			
Stoneville 2	6.62	6.58	6.52	6.44
Trice 90-1	6.72	6.67	6.51	6.42
Wilds 1	7.01	6.97	6.53	6.58
	Fineness, cm^2/mg.			
Stoneville 2	2.52	2.54	2.86	2.77
Trice 90-1	2.78	2.75	2.91	2.97
Wilds 1	3.49	3.52	3.67	3.64

It has been shown repeatedly that the flowering habit of the cotton plants is somewhat complex. Ewing (2) reported that the flowers gradually increase in number until a peak is reached, then a decline sets in. The distribution when smoothed out is very similar to the normal curve. This suggests that the flowering period might be divided into three time periods. Also that bolls harvested from flowers representing these time periods might show differences in the lint characters on account of variations in rainfall and temperature during the periods. Armstrong and Bennett (1) showed that the fibers of bolls from flowers of August 14 were shorter than those from flowers of August 21. The author (4) found that cotton fibers of the last picking were shorter than those of the first picking, the lint percentage was higher, seed weight lower, and lint index lower. Rajarman and Afzal (8) found that the length of fibers was shorter and the percentage of mature fibers lower on last pickings than on first pickings. Wadleigh (10) found significant differences in length of fibers from bolls of flowers dated July 1 and July 21 in his series A and B plants on which smaller increments of nitrogen were applied than on series C and D.

The procedure, therefore, would appear justified for dividing the fruiting period of the varieties into three time periods of flowering dates, as given in Table 8. In this table, approximately the first 3 weeks represent the ascending or first, period; the second two weeks or 10 days represent the peak, or second period; and all bolls from July 30 at Jackson and August 4 at Knoxville, the descending, or last period. Wilds 1, being a later variety, carries later time periods than the other two varieties as shown in the footnote to Tables 8, 9, 10, and 11. These time periods are relative and might vary some from year to year.

TABLE 8.—*Distribution, in percentage, of 4-lock and 5-lock bolls of Stoneville 2, Trice 90-1, and Wilds 1 for three maturity periods represented by known flowering dates at Jackson and Knoxville, 1932.*

Variety	Locks	Flowering dates					
		Jackson			Knoxville		
		July 1–18	July 19–29	July 30†	July 1–23	July 24 Aug. 3	Aug. 4†
Stoneville 2...	4	26.5	47.9	30.6	23.8	40.6	35.6
	5	12.9	66.1	21.0	17.4	62.6	35.6
Trice 90-1....	4	30.2	46.1	23.7	28.4	46.4	25.2
	5	22.3	57.7	20.0	18.8	56.8	24.4
Wilds 1*.....	4	21.9	43.3	34.8	18.7	42.4	38.9
	5	30.0	55.0	15.0	17.5	58.1	24.4

*Flowering dates for Wilds 1 at Jackson July 1–25, July 26–Aug. 4, and Aug. 5; at Knoxville July 1–25, July 26–Aug. 7, and Aug. 8.
†All flowers from July 3 and Aug. 4 to remainder of season.

The data of the three time periods are first distributed by 4- and 5-lock bolls, and the lint properties of each variety shown in Table 9.

TABLE 9.—*Length, strength, and fineness of cotton from 4-lock and 5-lock bolls of Stoneville 2, Trice 90-1, and Wilds 1 for three maturity periods represented by known flowering dates at Jackson and Knoxville, 1932.*

Variety	Flowering dates											
	Jackson						Knoxville					
	July 1–18		July 19–29		July 30†		July 1–23		July 24–Aug. 3		Aug. 4†	
	4-lock	5-lock	4-lock	5-lock	4-lock	5-lock	4-lock	5-lock	4-lock	5-lock	4-lock	5-lock
	Length, 32nds Inch											
Stoneville 2	30.7	30.8	32.8	32.0	30.7	31.0	33.9	32.9	31.6	31.2	31.9	31.1
Trice 90-1	31.0	30.6	32.0	32.2	30.6	30.5	32.7	32.1	30.8	30.5	29.9	30.1
Wilds 1*	38.0	38.3	37.4	37.8	37.2	37.3	39.0	38.9	36.9	36.7	33.0	33.0
	Strength, Lbs./Mg.											
Stoneville 2	7.19	7.05	6.54	6.63	6.42	6.36	6.48	6.31	5.97	5.87	6.36	6.37
Trice 90-1	7.36	6.96	6.56	6.57	6.15	6.23	6.68	6.71	6.31	6.22	6.54	6.56
Wilds 1*	6.88	6.91	6.94	6.99	7.20	6.97	6.17	6.16	6.65	6.89	6.44	6.65
	Fineness, cm.^{2}/mg.											
Stoneville 2	2.42	2.43	2.47	2.43	2.68	2.70	2.62	2.55	2.70	2.72	3.23	3.33
Trice 90-1	2.57	2.79	2.78	2.82	3.09	3.17	2.50	2.56	2.81	2.73	3.78	3.70
Wilds 1*	3.37	3.36	3.62	3.42	3.72	3.70	3.26	3.26	3.56	3.64	3.92	3.83

*Flowering dates for Wilds 1 at Jackson July 1–25, July 26–Aug. 4, and Aug. 5; at Knoxville July 1–25, July 26–Aug. 7, and Aug. 8.
†All flowers from July 3 and Aug. 4 to remainder of season.

Although there is a large difference in distribution of 4- and 5-lock bolls within the same period at both locations, yet there are no significant differences in the lint properties. It is seen further in this table that at Jackson the cotton fibers of both Stoneville 2 and Trice 90-1 are longest in the second period, strongest in the first period, and finest in the third period; Wilds 1 shows no significant difference except in fineness, which is highest in the third period. At Knoxville the cotton fibers of all three varieties are longest in the first period and finest in the third, or last, period. Wilds 1 is strongest in the second period, whereas Stoneville 2 and Trice 90-1 are strongest in the first period, but not significantly so.

The differences of the varieties by time periods in Table 9 are verified in Tables 10 and 11. In these tables, the bolls are allocated in the time periods by the nodes from which they were harvested. It is generally believed that bolls borne on the fourth node of the fruiting limb will receive less plant food than those on the first node, and that the lint character will thus be affected. The data in these tables, however, show no significant differences in the fiber characters of the bolls from the different nodes. There are only three exceptions out of the 180 values, and these may be due to chance. There is the matter of only two nodes shown in the first period. Eight of the 235 bolls at Jackson and 12 of the 251 bolls at Knoxville in this period came from the third and fourth nodes. These 20 bolls do not constitute a large enough number for comparison with those of nodes 1 and 2. During this first period most of the fruiting limbs have not made sufficient growth for production of third- and fourth-node flowers.

TABLE 10.—*Length, strength, and fineness of cotton from bolls of first, second, third, and fourth nodes on plants of Stoneville 2, Trice 90-1, and Wilds 1 for three maturity periods represented by known flowering dates at Jackson, 1932.*

Variety	July 1–18		July 19–29				July 30†			
	1st node	2nd node	1st node	2nd node	3rd node	4th node	1st node	2nd node	3rd node	4th node
					Length, 32nds Inch					
Stoneville 2	30.7	31.2	32.1	31.5	32.7	32.8	31.4	31.3	30.3	30.7
Trice 90-1	30.7	31.4	31.9	32.1	31.8	32.5	31.2	29.7	28.7	30.7
Wilds 1*	38.1	38.3	38.1	37.1	37.4	37.2	37.6	36.8	37.0	37.7
					Strength, Lbs./Mg.					
Stoneville 2	7.09	7.19	6.66	6.58	6.56	6.51	6.45	6.35	6.42	6.31
Trice 90-1	7.31	7.11	6.60	6.63	6.57	6.54	6.37	6.12	5.92	6.24
Wilds 1*	6.96	6.89	6.79	6.93	6.95	7.09	7.16	7.18	7.23	7.15
					Fineness, Cm^2/Mg.					
Stoneville 2	2.41	2.43	2.42	2.38	2.55	2.50	2.55	2.76	2.74	2.69
Trice 90-1	2.71	2.67	2.78	2.77	2.81	2.68	3.12	3.33	3.20	3.00
Wilds 1*	3.36	3.31	3.43	3.68	3.60	3.74	3.68	3.63	3.74	3.93

*Flowering dates for Wilds 1 July 1–25, July 26–Aug. 4, and Aug. 5.
†All flowers from July 3 and Aug. 4 to remainder of season.

TABLE 11.—*Length, strength, and fineness of cotton from bolls of first, second, third, and fourth nodes on plants of Stoneville 2, Trice 90-1, and Wilds 1 for three maturity periods represented by known flowering dates at Knoxville, 1932.*

Variety	July 1–23		July 24–Aug. 3				Aug. 4†			
	1st node	2nd node	1st node	2nd node	3rd node	4th node	1st node	2nd node	3rd node	4th node
					Length, 32nds Inch					
Stoneville 2	33.7	33.5	31.5	31.6	31.1	31.6	32.5	31.9	30.7	30.4
Trice 90–1	32.7	32.2	31.0	30.3	30.0	31.3	30.6	30.2	30.2	29.5
Wilds 1*	39.0	38.3	37.3	36.8	37.5	37.4	33.4	31.9	32.0	32.5
					Strength, Lbs./Mg.					
Stoneville 2	6.35	6.33	5.92	5.90	5.73	5.87	6.42	6.38	6.26	6.41
Trice 90-1	6.73	6.60	6.37	6.18	6.28	6.02	6.64	6.50	6.46	6.46
Wilds 1*	6.14	6.08	6.75	6.66	6.38	6.98	6.38	6.60	6.52	6.49
					Fineness, Cm²/Mg.					
Stoneville 2	2.52	2.50	2.70	2.72	2.75	2.69	3.32	3.26	3.27	3.40
Trice 90-1	2.47	2.63	2.78	2.70	2.83	2.92	3.66	3.86	3.68	3.77
Wilds 1*	3.30	3.15	3.58	3.54	3.61	3.75	3.80	3.94	4.00	3.99

*Flowering dates for Wilds 1 July 1–25, July 26–Aug. 7, and Aug. 8.
†All flowers from July 3 and Aug. 4 to remainder of season.

In Tables 12 and 13 the bolls of Stoneville 2 have been allocated by groups of plants in the three time periods, to represent length, strength, and fineness of lint. No significant differences are shown between these groups in the particular time period for each lint

TABLE 12.—*Length, strength, and fineness of Stoneville 2 when classified as to groups of plants and by the three maturity periods as represented by known flowering dates at Jackson.*

Maturity period	Group							
	1	2	3	4	5	6	7	8
				Length, 32nds inch				
July 1–18	32.2	31.3	28.6	31.5	31.8	29.7	29.6	32.1
July 19–29	33.9	32.0	31.6	33.1	32.7	32.6	31.6	32.3
July 30*	31.4	31.4	31.4	31.4	31.3	30.8	30.2	30.4
				Strength, lbs./mg.				
July 1–18	6.94	6.87	6.98	7.31	7.24	7.11	7.41	7.06
July 19–29	6.70	6.60	6.40	6.42	6.50	6.28	6.70	6.76
July 30*	6.26	6.45	6.20	6.41	6.36	6.14	6.65	6.32
				Fineness, cm²/mg.				
July 1–18	2.30	2.34	2.23	2.21	2.31	2.62	2.45	2.79
July 19–29	2.23	2.42	2.27	2.44	2.40	2.59	2.53	2.70
July 30*	2.34	2.56	2.38	2.82	2.57	3.01	2.83	2.94

*All flowers from July 3 to Aug. 4 to remainder of season.

TABLE 13.—*Length, strength, and fineness of Stoneville 2, when classified as to groups of plants and the three maturity periods as represented by known flowering dates at Knoxville.*

Maturity periods	Group					
	1	2	3	4	5	6
Length, 32nds Inch						
July 4–22	32.3	33.4	33.6	34.2	32.8	34.0
July 23–Aug. 3	30.1	30.9	31.6	32.1	32.0	31.8
Aug. 4*	30.3	30.4	31.7	31.8	30.9	32.8
Strength, Lbs./Mg.						
July 4–22	6.11	6.30	6.31	6.35	6.21	6.60
July 23–Aug. 3	5.70	6.07	5.88	5.93	5.80	6.08
Aug. 4*	6.22	6.31	6.13	6.38	6.10	6.92
Fineness, Cm^2/Mg.						
July 4–22	2.38	2.59	2.50	2.76	2.47	2.52
July 23–Aug. 3	2.58	2.72	2.70	2.80	2.72	2.70
Aug. 4*	2.90	3.33	3.17	3.20	3.49	3.52

*All flowers from July 3 to Aug. 4 to remainder of season.

character. There are large and significant differences between time periods as given in preceding tables. The other two varieties were treated in the same manner and analysis of variance calculated. The results are shown in Table 14. In this table the high F values for time periods are readily observed. Every case shows higher F value than that for the 1% level given in Snedecor's tables (9). The F values for groups are very little higher than the one for the 1% level in 5 cases out of the 18.

TABLE 14.—*Significance of differences between time periods and between groups in length, strength, and fineness of Stoneville 2, Trice 90-1, and Wilds 1 as measured by values of F.*

	Jackson				Knoxville			
	F 1%	Length F values	Strength F values	Fineness F values	F 1%	Length F values	Strength F values	Fineness F values
Stoneville 2								
Time periods	6.51	10.17	41.36	13.17	7.56	26.85	22.00	48.42
Groups	4.40	2.29	2.82	7.50	5.64	6.30	4.50	2.71
Trice 90-1								
Time periods	6.51	27.39	28.04	9.18	7.56	36.03	4.52	16.35
Groups	4.40	13.80	2.37	3.41	5.64	2.98	1.36	3.33
Wilds 1								
Time periods	6.51	7.14	7.82	9.10	7.56	16.50	22.30	76.66
Groups	4.40	4.63	5.73	6.60	5.64	4.55	5.90	1.33

Finally, Table 15 shows the differences in each lint character when grouped by time periods for the variety. The same conclusions are derived from this table as from Tables 9 to 14, namely, that significant differences in lint characters of the variety are shown for different time periods. The means may be tested by values of 1.3 32nds inch for length, 0.55 pound per milligram for strength, and 0.31 per square centimeter for fineness. All varieties had finest lint in the third period at both locations. Both Stoneville 2 and Trice 90-1 had strongest lint in the first period at the two locations, whereas Wilds 1 had strongest lint in last period. All had longest lint in the first period at Knoxville, while at Jackson longest lint came from the second period, except in the case of Wilds 1.

TABLE 15.—*Length, strength, and fineness of cotton from bolls on all groups of plants of Stoneville 2, Trice 90-1, and Wilds 1 at Jackson and Knoxville, 1932 for three maturity periods represented by known flowering dates.*

Variety	Jackson			Knoxville		
	July 1–8	July 19–29	July 30†	July 1–23	July 24–Aug. 3	Aug. 4†
			Length, 32nds Inch			
Stoneville 2	30.8	32.4	30.9	33.4	31.4	31.5
Trice 90-1	30.8	32.1	30.6	32.4	30.7	30.1
Wilds 1*	38.2	37.6	37.2	39.0	36.8	33.0
			Strength, Lbs./Mg.			
Stoneville 2	7.12	6.59	6.39	6.40	5.92	6.36
Trice 90-1	7.16	6.57	6.19	6.78	6.27	6.56
Wilds 1*	6.90	6.86	7.03	7.16	6.77	6.55
			Fineness, Cm²/Mg.			
Stoneville	2.42	2.45	2.72	2.59	2.72	3.28
Trice 90-1	2.68	2.80	3.13	2.53	2.77	3.74
Wilds 1*	3.36	3.52	3.72	3.26	3.60	3.88

*Flowering dates for Wilds 1 at Jackson July 1–25, July 26–Aug. 4, Aug. 5; at Knoxville July 1–25, July 26–Aug. 7, and Aug. 8. All flowers from Aug. 5 to remainder of season.

DISCUSSION

Large variations in all three lint characters are shown in Tables 1 to 15. Such variations are associated initially with bolls on the plants, and also are found between plants and between groups of plants. Many results heretofore attributed to instruments, and to instrument operators, may be traced to careless sampling of cotton in the field. No machine has been invented that will give an adequate mix of fibers from which small samples must be drawn for measurement. It should be recalled that only a few grams of cotton are taken for a length measurement and only a few milligrams for strength and fineness measurements. Fibers having extreme values, however, can be partly eliminated when attention is given to adequate field sampling.

The small differences between the group means (Tables 2 and 3) and the true means of the bolls might suggest to agronomists the

possibility of taking a composite sample from 10% of the plants in a row—in this study, five plants at Jackson and seven plants at Knoxville. It is shown in Tables 12 and 13, however, that a composite sample of this kind would contain extreme values. Three composite samples, representing the three periods, should give more accurate measurements of the variety or treatment.

The wide variation of the plants within the groups of Table 4 might lead one to suspect that the population of Stoneville 2 is not homogeneous. The variances of the groups in Table 4 range from 4.25 in group 5 to 23.69 in group 4. Employing the method of Bartlett as given by Hayes and Immer (6), a chi square of 4.30 is obtained. For 4 degrees of freedom this value would be probable about 80% of the times. Hence, this population is homogeneous; and so are the other populations for strength and fineness, when tested by this method. It is the opinion of the author that the method is not as rigorous as it should be, but suggestions for improvement would have to await further investigation.

The variations of bolls on single plants in Table 5 are of serious concern to the plant breeder. One or two bolls would constitute a 10% sample on almost all plants. The data in Table 5, however, do not justify this small sample, and these data are a fair example of the population of bolls on single plants in this study. At least four bolls should be taken as a sample for the plant. Here again the differences due to time periods should receive some consideration. Bolls at bottom and top of plant should be avoided. The data in Tables 9 to 15 show that such bolls might cause undue bais in representing the plant. This bias might be diminished considerably in the establishment of inbred lines by limiting the period of selfing to the 3 or 4 weeks when the plant is in its most productive phase.

In varietal and fertilizer tests and samples of cotton for spinning tests more accurate results would come from samples of three pickings than from the one now obtained by most agronomists. A few flowers dated once each week would help in the selection of picking times.

The relation which environment bears to the lint characters of each period cannot be discussed in this paper. The establishment of this relation and its uniformity should be of value to the spinner in obtaining cotton of specific lint characters. The spinner might be interested primarily in strength of fibers, so that in the area around Jackson in 1932 he would have chosen bales from first pickings; or if interested in length, bales from second picking; or in fineness, bales from third pickings.

SUMMARY

Measurements of length, strength, and fineness were taken on 1,012 bolls of three varieties at Jackson and 1,313 bolls of the same varieties at Knoxville.

These bolls were also designated as to plant, lock, node number, and dates of flowering.

They are allocated by groups of plants, single plants, lock numbers, node numbers, and time periods of flowering dates. Sampling procedures are suggested on the bases of these allocations.

The time periods for growth of cotton give significant differences in the three lint characters of length, strength, and fineness.

Structural differences, such as 4- and 5-lock bolls, and node number can be ignored in sampling cotton.

The two varieties Stoneville 2 and Trice 90-1 gave similar results in their lint characters, but their behavior is different from that of Wilds 1, a long-staple, and later-maturing cotton.

On the basis of these studies, three pickings are justified for accurate sampling by an agronomist and at least four bolls harvested from the middle of plant by the breeder.

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The Value of Improved Land Use as Measured by Preliminary Data on Relative Infiltration Rates[1]

PAUL J. ZWERMAN[2]

DATA reported in this paper were collected during the course of an infiltration survey made on that part of the drainage basin of the Coosa River above Rome, Ga. They afford an opportunity to compare the results of ordinary practices of land use with alternative improved practices. The specified practices compared are as follows: Row crops versus lespedeza, idleness versus kudzu, and improper forest management versus proper forest management.

PLAN OF SURVEY

The early investigations directed by Musgrave (7)[3] showed the practical significance of determining relative infiltration rates. The Coosa River infiltration survey was a necessary step in determining infiltration rates for certain small component drainage basins. These smaller basins were considered to be representative of the entire Coosa River drainage.

Soils of the large drainage basin belong mainly to three soil associations which are fully described in the 1938 Yearbook of the U. S. Dept. of Agriculture. They are briefly described here. The Decatur-Dewey-Clarksville soil area is characteristic of the limestone valley. The Dewey soils have brown surface soils and reddish-brown, firm, friable subsoils. Clarksville soils have light-gray surface soils and yellow, friable subsoils. The Armuchee soils, also part of this association, are variable in profile characteristics. In general, they have brown silt loam surface soils and brownish-yellow silty clay subsoils. The Cecil-Appling Association is represented by the Cecil soils. They are characterized by either gray sandy loam or red clay loam surface soils, underlain by red, stiff but brittle clay subsoils. Porters-Ashe soil areas are considered to be Gray-Brown Podzolic soils. They are represented in the watershed by Talladega loam, which has a friable surface of reddish brown loam. The Talladega subsoil is a loam or clay loam.

The infiltration measurements were made on specific plots of representative soils within these broad soil associations. The plots were selected within the small representative drainage basins by land capability classes. Field conditions representative of land classes III and VII were selected. The soil types were also selected to be representative. In general, class III land was made up of the deeper, more productive soils, on moderate slopes and only moderately eroded. This land was suitable for cultivation. The sites on class VII land were on the more shallow, less productive soils. The soils were all strongly sloping and moderately or severely eroded. This land was not suitable for cultivation. Certain forested areas in this land class showed little or no erosion.

Relative infiltration rates for the ordinary as opposed to the improved practices were determined by selecting sites representative of each condition. Tentative sites were selected by the infiltrationist in charge. These sites were then approved or rejected by a committee made up of a soil scientist, a forester, and an agronomist who were responsible for their respective fields on the major Coosa River Flood Control Survey. An attempt at randomization of the location of the individual plots within the selected area was made by throwing a stone over one's

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[1]Contribution from the U. S. Soil Conservation Service. Data from a flood control survey of the Coosa River Watershed, Cartersville, Ga., by the U. S. Dept. of Agriculture. Infiltration surveys planned by C. H. Diebold, Forest Service. Measurements by a joint field party, Forest Service and Soil Conservation Service, with W. A. Weld, U. S. Soil Conservation Service hydrologist, in charge. A. E. Brandt assisted in the statistical interpretations. Received for publication July 22, 1946.

[2]Assistant Soil Scientist in charge of infiltration survey field party.

[3]Figures in parenthesis refer to "Literature Cited", p. 140.

shoulder and placing the plot where the stone fell. The contrasting selected areas were usually closely adjacent and chosen to be as nearly identical as could be found with respect to soil type, degree of erosion, and percentage of slope. It was not assumed that the sites were paired. The unequal number of tests on the ordinary as opposed to the improved practices resulted from the circumstance that certain of the small drainage basins fell entirely within one category of land use. Thus, one small basin was within the boundary of a national forest, where it was thought necessary to compare improved practices on old field pine with improved practices on hardwoods. In a like manner more idle than kudzu sites were studied.

The growing of continuous row crops was the prevailing practice on the cultivated class III land. The improved practice studies was a 3-year rotation of row crops, small grain seeded down to Lespedeza, and Lespedeza grown in the form of contour strip rotation with a complete water disposal system (terraces with proper outlets). All infiltration tests with improved practice for this class of land were made on second year lespedeza. Infiltration tests with ordinary practice were made on land which cotton on stalks were standing. The steeper, more severely eroded land considered to be class VII was subdivided because at the beginning of improvement some of it was in forest and some idle. Unimproved forest had from 30 to 70% cover of trees (stocking) and no fire or grazing control. Improved forest had 70% or more stocking, complete fire control, and no grazing. Ordinary idle sites were made up of land that was "resting". Its vegetation was mostly broom sedge and annual weeds. Improved idle consisted of kudzu that had been established for 5 years or more. These areas were being mowed regularly for hay.

TECHNIC OF INFILTRATION MEASUREMENT

The data reported here were collected by using the FA type infiltration equipment. Type F equipment was used to obtain supplementary data. Comparative results for the two types have been discussed by Diebold (3). He also describes the type rainfall-minus-runoff curve obtained with the FA apparatus. The type F and the type FA infiltrometers differ principally in the size of plot and in the area wetted. In the former, a plot 6×12 feet with a border area 3 feet in width is wetted, whereas, in the latter a plot 1×2.5 feet with a border area 1.5 feet in width is wetted. Metal border plates are used to delimit the plot boundaries. In both instances the plots and wetted areas are enclosed by tents.

The technique of measuring infiltration was essentially that described in detail by Rowe (8); however, the following modifications were made:

1. The nozzle used was of the large drop "F" type as developed by the Hydraulic Laboratory of the Bureau of Standards. This type was selected as standard for all flood control surveys because it produces drops which are comparable in size to those of natural rain (3.2 to 5.0 mm in diameter). Laws (6) has been able to show that a definite relation exists between the beating action-energy of rain drops and the resulting infiltration rates. Four of these nozzles were used. Each delivered 1.75 to 2.25 inches per hour. All four were mounted on one head with individual cut-off valves such that any combination of them could be used at any time. The tops of the nozzles were 31 inches above the ground and were situated 3 inches outside the plot at the center line. They were inclined toward the plot at a 7 degree angle.

2. Pressure was maintained at 15 pounds per square inch by use of a centrifugal pump and an air pressure surge tank.

3. The length of plot was increased to 30.5 inches horizontal distance so that runoff could be read in 0.01 inch per hour by minute intervals. Measurements were made with 250-, 500-, and 1,000-cc graduated cylinders.

4. City water from adjoining towns was used.

5. No vegetation was clipped from the plots.

6. Ten 1-minute calibration readings were made at the beginning and end of each run. If these gave a rainfall error greater than 5% of the mean value, the run was discarded. Approximately 10% of them were rejected for this reason. Because of the 5% uncontrollable variation in rainfall rate (based on a 2-inch delivery at the nozzle), all relative infiltration rates were rounded to the nearest 1/10 inch.

7. A first or "dry" run was made and approximately 24 hours later a second or "wet" run was made on the same site. The terms "wet" and "dry" are used here in a relative sense. All soils were moist. However, they were comparatively "dry" before the first or "dry" and comparatively "wet" before the second or "wet" run. Qualitative observations of initial soil moisture were recorded for all runs. However, all tests reported were made between January 15 and April 15, 1941, a period of frequent and well-distributed rainfall during which soils remained moist. All runs were continued for 90 minutes; in some cases longer. The more absorbtive sites usually required a longer time to "level off". Runoff measurements were made every minute for the first 30 minutes, then at 2-minute intervals for the next 10 minutes, and finally at 4-minute intervals through at least a 90-minute time interval for the test, or until such time as the runoff rate was constant for a period of 40 minutes. These rates subtracted from the "rainfall" of the wet and dry runs gave the respective final relative infiltration rate reported in tables 1 and 2.

The data were plotted in the field as collected. In order to insure a precipitation excess, rainfall intensities were increased until a runoff of ½ inch per hour resulted during the first 30 minutes. In the case of relative infiltration rates greater than 2 inches per hour, an excess of 1 inch in 30 minutes was applied. In addition to the qualitative observations on soil moisture, a complete soil description was recorded at each site. Supplementary qualitative observations were made on soil-crust formation, turbidity of runoff, and apparent lateral seepage. Seepage or subsurface lateral movement was determined by boring a series of holes at right angles to the outside walls of the tent. (See technic of Infiltration Measurement.) The approximate distance in inches that water had seeped laterally could thus be observed. A duplicate sample was taken from the surface soil of a representative test plot of kudzu on Cecil clay loam and Clarkesville cherty silt loam. These samples were analyzed for organic matter.

EXPERIMENTAL RESULTS

The data are presented in Tables 1 and 2.[4] No attempt has been made to give a statistical expression to the supplementary qualitative observations nor to the dry infiltration rates. However, the data on wet infiltration rates have been treated statistically to examine the differences in infiltration between improved and unimproved land use practices under the three cover conditions. On cultivated land the improved practice of second year lespedeza resulted in better infiltration (1.08 inches per hour) than that with row crops grown under ordinary practice (0.21 inch per hour). Infiltration under kudzu (2.92 inches per hour) was better than on idle land (0.24 inch per hour). Less difference was found, however, between proper management (2.70 inches per hour) and poor management (1.12 inches per hour) on forested land. It should be noted that the infiltration rate for soil under kudzu was as high as that on forested soil.

INTERPRETATION OF EXPERIMENTAL RESULTS

The relative infiltration rates give a quantitative evaluation of the efficiency of various land use treatments in retarding runoff. The qualitative data indicate that, in general, the lower rates of infiltration are associated with the presence of a soil crust and turbidity of runoff. This confirms the earlier observations of Kelly and Duley (5) that crust formation is important regardless of soil type. Higher rates are associated with the absence of soil crust and lack of turbidity of runoff. Also, they are frequently observed where there is noticeable seepage from the test plot. The kudzu tests are a notable exception

[4]Analysis for organic matter made by T. C. Peele and O. W. Beale.

to this observation. As Musgrave (7) has observed, there may be more or less seepage regardless of the method of measuring infiltration, particularly if buffer areas are not used.

TABLE 1.—*Relative infiltration rates in inches per hour by land use and soil types on land suitable for cultivation.**

Land use and crop	Soil types			General mean rate by land use
	Dewey silt loam	Clarkesville cherty silt loam	Cecil sandy loam	
Unimproved: Cotton stalks	W 0.7 0.6 D 0.6 1.3 Surface crust; turbid runoff; no apparent seepage	0.2 0.2 0.0 0.1 0.0 0.2 0.5 0.5 0.1 0.3 0.4 0.4 Surface crust; turbid runoff; no apparent seepage	0.2 0.1 0.1 0.1 0.3 0.2 0.2 0.2 0.6 0.4 0.5 0.1 0.3 0.3 0.1 0.4 Surface crust; turbid runoff; no apparent seepage	0.21 0.42
Improved: Second year lespedeza	W 0.5 0.6 D 1.1 No surface crust; turbid runoff; no apparent seepage	3.4 2.8 0.1 1.8 1.5 — No surface crust; clear runoff; approximately 20 inches lateral seepage	0.5 1.6 0.5 0.1 1.0 2.3 0.1 0.4 2.0 0.3 1.7 1.5 0.2 0.2 1.4 2.6 0.3 1.0 1.6 0.5 Surface crust; turbid runoff; approximately 20 inches lateral seepage	1.08 1.18

*Class II land; all soils of comparatively smooth topography and moderate erosion. Successive infiltration runs are shown in sequence. The "W" and "D" indicate wet and dry runs, respectively.

Duley and Domingo (4) have shown that this seepage error may be 400 to 500% under certain circumstances. If a soil crust prevents infiltration, there can be little seepage. When there is no crust, the infiltered water moves laterally at the first relatively impervious soil horizon encountered. Field examination of the kudzu plots after the tests were made indicated that the kudzu plants possessed well-developed root systems to a depth of 3 feet or more. These root systems apparently contributed to making the lower horizons more permeable to water. The 3.1% of organic matter on the Cecil clay loam and the 1.5% on Clarkesville cherty silt loam compare very favorably with the accumulations reported by Bartholomew (2). This organic matter content is considerably more than that ordinarily found on cotton land. There was every evidence of deep vertical penetration of soil organic matter and soil moisture with no apparent evidence of lateral seepage.

The rates of infiltration under lespedeza appear low in the light of the known efficiency of lespedeza in preventing runoff (1). A partial explanation for this low rate can probably be found in the fact that excessive rates of rain were applied for relatively prolonged periods as compared to conditions of natural rainfall. Flood-producing storms were simulated. It must also be noted that this is second year lespedeza and is, perhaps, a more efficient soil-conserving cover than first year lespedeza, grain, and row crops. These latter crops would almost certainly give a lower relative rate of infiltration. The

TABLE 2.—*Relative infiltration rates in inches per hour by land use and soil types on land not suitable for cultivation.**

Land use		Soil types					General mean rate by land use
		Dewey silty clay loam	Clarkesville cherty silty clay loam	Armuchee shale loam	Cecil clay loam	Talladega loam	
Idle:							
Improved Kudzu	W* D		0.3 1.3 6.4 4.2 0.6 2.3 6.2 6.5 No surface crust; clear runoff; no apparent seepage 1.5% organic matter in plow layer		4.2 4.0 2.6 0.4 5.1 4.2 6.3 1.3 No surface crust; clear runoff; no apparent seepage; 3.1% organic matter in plow layer		2.92 4.06
Unimproved Broom sedge and weeds	W D		0.1 0.6 0.1 0.1 1.1 0.7 Surface crust; turbid runoff; no apparent seepage	0.3 0.2 0.1 0.2 0.1 0.1 Surface crust; turbid runoff; no apparent seepage	0.3 0.4 0.1 0.2 0.1 0.3 0.4 0.2 1.0 0.2 0.2 0.3 0.2 0.3 0.5 0.3 Surface crust; turbid runoff; no apparent seepage		0.24 0.38
Forest:							
Poor management	W D	1.2 2.5 2.0 3.5 No surface crust; turbid runoff; no apparent seepage		1.0 0.6 0.6 0.8 0.9 0.9 0.8 0.8 0.6 1.2 1.0 1.2 1.2 0.9 No surface crust; turbid runoff; no apparent seepage	0.3 0.2 0.3 0.1 0.6 0.6 0.5 0.2 Surface crust; turbid runoff; no apparent seepage	3.6 5.0 0.4 0.3 0.7 4.3 5.6 0.8 0.8 1.0 Surface crust; turbid runoff; no apparent seepage	1.12 1.49
Proper management	W D	2.8 1.0 3.8 1.6 No surface crust; clear runoff; no apparent seepage	2.4 4.3 4.8 0.8 3.3 4.9 5.5 1.8 No surface crust; clear runoff; approximately 36 inches seepage	1.9 1.0 3.9 3.8 7.7 5.5 2.3 1.3 2.3 1.0 4.2 3.3 5.5 5.5 3.5 – No surface crust; clear runoff; approximately 12 inches seepage	0.3 0.4 0.3 0.1 0.4 0.3 0.6 1.2 0.8 0.2 0.1 0.2 No crust; clear runoff; approximately 48 inches seepage	3.1 2.1 0.8 1.4 3.7 1.1 5.3 3.2 6.7 8.4 3.4 3.5 – 2.4 3.3 3.6 6.1 4.0 6.8 8.4 No crust; clear runoff; no apparent seepage	2.70 3.24

*Successive infiltration runs are shown in sequence. The "W" and "D" indicate wet and dry runs, respectively.

extreme variability of the forest rates is representative of the wide variation in ground cover and erosion to be found in the forested area.

SUMMARY AND CONCLUSIONS

One hundred and one infiltration tests were made with the FA type infiltrometer. These tests were made on land suitable for cultivation and on land not suitable for cultivation.

On land suitable for cultivation, improved practice of second year lespedeza was compared with the ordinary practice of row crops. The significantly different mean infiltration rates were 1.0% and 0.21 inch per hour, respectively. Land not suitable for cultivation was surveyed as forested and idle land. Poor forest management gave a mean relative infiltration rate of 1.12 inches per hour; good forest management gave a rate of 2.70 inches per hour. These values, however, were not significantly different at the 5% level because of the extreme variability of their relative infiltration rates.

On idle sites, broom sedge and weeds was the ordinary practice and kudzu was considered the improved practice. The mean rates were 0.24 and 2.92 inches per hour, respectively. The surprisingly high mean rate of infiltration on land given over to kudzu production was associated with a high content of soil organic matter and a deep vertical penetration of soil moisture. Field examination of the soil on the kudzu sites indicated a marked improvement in physical structure.

While the results reported here may not be considered conclusive, they certainly are indicative that southeastern agronomists and farmers could quickly improve much idle land by means of kudzu. Lack of seed of improved varieties, and of practical "know-how" as to curing have been limiting factors in kudzu production.

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The Effect of Legumes on the Percentage of Crude Protein in Orchard Grass and Bromegrass at Beltsville, Md., During 1945[1]

R. E. Wagner and H. L. Wilkins[2]

The value of legumes in pasture mixtures is well recognized, but some of the specific effects of such associations and their practical applications are still somewhat obscure. It is generally conceded that legumes improve the quality of pastures through an increase in the protein content of the mixed herbage. Some investigators have assumed that legumes exert a beneficial effect in increasing the protein content of the nonlegume component of the mixture. However, the data to substantiate these assumptions are not numerous.

As early as 1911, Lyon and Bizzell (5)[3] reported experiments in which they found that legumes increased the protein percentage in associated nonlegumes. In 1912, Lipman (4) reported similar but more conclusive findings which strongly indicated that nonlegumes benefited when grown in association with legumes. For several years following these early contributions there appeared to be little interest in the subject. In the middle and late 1930's, Fergus (2), Johnston-Wallace (3), and Madhock (6) obtained results similar to those of the earlier workers. More recently Aberg, Johnson, and Wilsie (1) found that nitrogen percentages were not significantly different for grasses grown in association with legumes and grown alone. However, these results were obtained from new seedlings on a highly productive soil. Wilson (7) gives an excellent review of the work done on the subject and related phases up to 1940.

Further investigations are needed to determine the actual effects of various legumes on associated nonlegumes and their practical significance. The preliminary data herein reported are from studies being conducted at the Bureau of Plant Industry Station, Beltsville, Md.

PROCEDURE

Plots for this study were selected from an area seeded in the fall of 1942 to test the adaptation and production of a number of grass-legume mixtures. As it was possible in 1945 to find comparable plots containing different amounts of legumes in association with orchard grass and bromegrass, this afforded an opportunity to study the influence of legumes on associated grasses. One series of plots which had been clipped to simulate grazing during the course of the original experiment and another series which had been harvested in the hay stage each year, were chosen for this study.

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Beltsville, Md. Received for publication July 22, 1946.

[2]Associate Agronomist and Assistant Chemist, respectively. The authors gratefully acknowledge the many helpful suggestions of M. A. Hein, Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering. The plots used in this study were selected from a group of plots inaugurated by Paul R. Henson, Agronomist, Division of Forage Crops and Diseases, Stoneville, Miss.

[3]Figures in parenthesis refer to "Literature Cited", p. 145.

The entire area had been uniformly limed, fertilized, and manured prior to seeding in 1942 with amounts believed to be sufficient for optimum growth. Ladino clover and Korean lespedeza were the legumes originally sown in the pasture mixtures, and Ladino clover and alfalfa were seeded in the hay mixtures. Even though the legume stands in 1945 were poor in some cases, all remaining plants produced particularly vigorous growth, indicating a high fertility level of the field. Rainfall during the months of April through September was 12.12 inches above the long-time average of 23.03 inches for the period. That the season was unusually early was indicated by the fact the first hay crop was cut on May 12.

In pasture plots, five comparisons were possible between orchard grass in association with Ladino clover and orchard grass alone. Adjacent plots were compared in each case. Eight cuttings were made on these plots during the 1945 season, but chemical analyses were made on the seventh and eighth only. Korean lespedeza was originally seeded in the plots considered as orchard grass alone in this comparison, but it had practically all disappeared by 1945. Representative samples of grass were separated from the mixtures in the pasture plots in each case to use in making the protein determinations. Amounts of Ladino clover in the pasture plots were not determined by plant separations but were estimated, on the basis of plant cover, to comprise 40 to 50% of the herbage. This applies to the data in Table 1 only, the data on the hay plots being obtained from plant separation.

In the hay series, plots containing varying percentages of Ladino clover and alfalfa in mixtures with orchard grass and bromegrass were selected for analysis. Unfortunately, it was impossible in all cases to find plots with as wide a spread in legume percentages as would be desirable. Actual legume percentages in the hay plots were determined on a dry weight basis from plant separations and are recorded as such in Tables 2 and 3.

RESULTS AND DISCUSSION

In any consideration of the data herein presented, it must be borne in mind that they are preliminary, and final conclusions will be based on further results obtained from studies now in progress.

The data obtained from the pasture plots, in which comparisons were made between orchard grass in association with Ladino clover and orchard grass alone, are given in Table 1. Without exception, the protein content of the grass was higher when grown with Ladino clover than when grown alone in adjacent plots. The grass harvested

TABLE 1.—*Percentage of crude protein in orchard grass harvested at pasture stage of growth from plots containing grass alone and grass in association with Ladino clover.*

Seventh cutting, July 25, 1945			Eighth cutting, Aug. 22, 1945		
Orchard grass grown alone*	Orchard grass grown in association†	Difference	Orchard grass grown alone*	Orchard grass grown in association†	Difference
19.32	23.14	3.82	16.71	19.82	3.11
21.05	26.24	5.19	16.73	20.46	3.73
20.06	24.50	4.44	16.68	19.63	2.95
21.30	27.47	6.17	18.39	21.63	3.24
20.16	24.76	4.60	17.98	21.33	3.35
Av. 20.38	25.22	4.84	17.30	20.57	3.27

*These plots contained a trace of Korean lespedeza.

†Plant cover estimates indicated that these plots contained from 40 to 50% Ladino clover. Crude protein determinations were made on the grass component only.

on July 25 from the five plots of grass-Ladino clover mixtures averaged 25.22% protein as compared to 20.38% for the grass grown alone, or an average increase of 4.84% apparently due to the association with Ladino clover. In the following crop harvested on August 22 from the same plots all protein percentages were lower than in the preceding crop, but similar differences persisted. Grass grown in association contained an average of 20.57% protein, whereas that grown alone averaged 17.30%, a difference of 3.27%. The height of the grass was approximately 5 inches, which was believed to be an optimum pasture stage of growth, at the time of both cuttings.

In Tables 2 and 3 are given the data on orchard and bromegrass harvested from hay plots containing varying percentages of Ladino clover and alfalfa. Correlation coefficients between the percentage of legume and percentage of protein in the associated grass are also contained in these tables. In general, the protein content of the grass increased as the percentage of associated legume increased. The N values are relatively small and the data are not in the order expected in every individual case, but nevertheless the trend is apparent. Two of the correlation coefficients are significant at the 1% level, six at the 5% level, and four are nonsignificant. The r values indicate considerably closer correlations in the first crop than in the second.

The protein content of the orchard and bromegrass was considerably lower in all cases in the first hay crop than in the second. This might be explained, at least in part, by the rather advanced stage of growth at the time of the first harvest and the typically more leafy type of growth of the aftermath comprising the second harvest. The greater relative growth of the legumes after the first cutting, as indi-

TABLE 2.—*Percentage of crude protein in bromegrass and orchard grass when harvested at hay stage of growth from plots containing varying amounts of Ladino clover.*

First hay crop, May 12, 1945				Second hay crop, June 21, 1945			
Bromegrass mixture		Orchard grass mixture		Bromegrass mixture		Orchard grass mixture	
Ladino clover, % (1)	Protein in bromegrass, % (2)	Ladino clover, % (3)	Protein in orchard grass, % (4)	Ladino clover, % (5)	Protein in bromegrass, % (6)	Ladino clover, % (7)	Protein in orchard grass, % (8)
12.1	13.51	5.5	10.04	59.5	21.50	44.6	16.11
12.4	12.71	7.7	9.72	48.4	19.98	51.1	16.22
13.7	12.91	11.4	11.69	33.0	19.95	76.7	18.19
18.6	12.98	11.7	10.04	56.3	20.85	46.4	16.49
19.9	16.06	14.9	12.03	45.4	21.34	49.2	15.57
20.0	16.49	26.1	14.36	62.5	24.06	75.9	17.26
41.8	19.83	31.5	12.29	75.4	23.23	63.1	16.84
—	—	31.8	14.19	—	—	67.0	20.73

Correlation coefficients:
Significant at 1% level: between columns 1 and 2, r=.91, columns 3 and 4, r=.85.
Significant at 5% level: between columns 5 and 6, r=.78.
Nonsignificant: between columns 7 and 8, r=.62.

TABLE 3.—*Percentage crude protein in bromegrass and orchard grass when harvested at hay stage of growth from plots containing varying amounts of alfalfa.*

First hay crop, May 12, 1945						Second hay crop, June 21, 1945					
Bromegrass mixture			Orchard grass mixture			Bromegrass mixture			Orchard grass mixture		
Total legume,* % (1)	Alfalfa, % (2)	Protein in bromegrass, % (3)	Total legume,* % (4)	Alfalfa, % (5)	Protein in orchard grass, % (6)	Total legume,* % (7)	Alfalfa, % (8)	Protein in bromegrass, % (9)	Total legume,* % (10)	Alfalfa, % (11)	Protein in orchard grass, % (12)
14.8	6.3	11.00	22.4	22.4	11.82	74.4	53.7	19.87	46.4	46.4	17.37
30.4	29.1	11.43	24.0	20.7	11.56	71.1	67.6	20.34	60.6	49.5	17.56
35.9	33.2	13.26	24.8	22.9	10.54	78.3	76.7	24.08	66.5	64.7	17.10
39.7	37.7	13.36	27.1	20.1	12.06	72.5	72.5	20.51	63.3	52.3	17.34
41.4	38.8	13.12	28.3	19.2	10.78	74.1	70.6	22.81	56.0	42.2	16.79
55.9	47.9	13.54	28.3	27.4	12.51	77.8	59.4	22.90	66.3	66.3	17.24
56.2	56.2	18.06	41.3	41.3	11.55	73.7	73.7	22.38	68.4	68.4	18.07
—	—	—	43.2	37.9	16.55	—	—	—	61.3	58.8	18.40
—	—	—	45.7	43.3	15.29	—	—	—	65.7	62.2	18.38

*Includes total of Ladino clover and alfalfa where Ladino clover had volunteered or crowded into the alfalfa plots.

Correlation coefficients:

Significant at 5% level: between columns 1 and 3, r = .79, columns 2 and 3, r = .83, columns 4 and 6, r = .70, columns 5 and 6, r = .69, columns 7 and 9, r = .78.

Nonsignificant: between columns 8 and 9, r = .49, columns 10 and 12, r = .31, columns 11 and 12, r = .45.

cated by the higher percentage of legume in the second crop, might also be a factor in increasing the protein content.

An interesting feature of the data is the higher protein content of bromegrass as compared to orchard grass. This is particularly striking in both the first and second crops of the Ladino clover mixtures, but only in the second crop of alfalfa mixtures. In the first cutting the bromegrass was just beginning to head, whereas the orchard grass was further advanced and past the best hay stage. However, in the second crop neither species was beginning to head and both were considered to be in about the same stage of growth.

The data from the first crop show a higher average protein content for bromegrass grown in association with Ladino clover than where it was grown with alfalfa, even though the percentage of legume, on a dry-weight basis, in the Ladino plots was considerably less than in the alfalfa mixtures. The average protein content of orchard grass with Ladino was slightly less than with alfalfa, but the percentage of legume in the Ladino mixtures was also lower. These results would suggest that Ladino clover might be more effective than alfalfa in increasing the protein content of the spring growth of associated grasses. The significance of these results is being studied further in tests now underway.

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The Influence of Sulfur on the Yield and Composition of Clovers Fertilized with Different Sources of Phosphorus[1]

ROGER W. BLEDSOE AND R. E. BLASER[2]

EXPERIMENTAL evidence is accumulating in the United States to support further the assumption of the Russian chemist, Bogdanor, that the natural supply of sulfur might not be sufficient everywhere for the normal growth of some crops. Sulfur-deficient areas and growth responses to applications of sulfur have been reported for 12 states and from 3 provinces in Canada. Sulfur deficiencies may also exist in other states since it has been shown by improved techniques that the annual amount of sulfur supplied by precipitation in rural areas might be insufficient to replenish that lost by leaching and removed by crops (1, 7).[3]

The annual amount of sulfur obtained through rainfall in Florida is not known, but it is no doubt low and may be expected to range between 3 and 6 pounds per acre in the Gainesville area as reported for rural sections of southern Alabama (7). Due to the high annual rainfall and leaching, with the possibility of a relatively low amount of sulfur in the atmosphere of that area, it was assumed that the available soil sulfur might be insufficient for maximum yields of leguminous plants. Furthermore, reported results show that clover yields frequently were increased on some soil types when superphosphate was used as the source of phosphorus or when other forms of phosphorus were supplemented with superphosphate (3). The increased yields might have been due to the sulfur of the superphosphate rather than the availability of phosphorus since the clovers did not differ appreciably in phosphorus content regardless of the source of phosphorus.

This paper presents some preliminary results of a detailed experiment on the effects of sulfur fertilization on the growth and chemical composition of two clovers.

EXPERIMENTAL PROCEDURE

The experiment was established on a virgin Leon fine sand which, at a depth of 0 to 4 inches, had a pH value of 4.3 and a base exchange capacity of 6 m.e. per 100 grams of dry soil. The soil is typical of a large portion of the flat pine land in peninsular Florida.

The fertilizer treatments were applied to plots randomized in three replicated blocks. A uniform application of high calcium limestone at the rate of 2,600

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[3]Figures in parenthesis refer to "Literature Cited", p. 152.

pounds per acre was disced into the soil over the entire experimental area. Fertilizers representing four sources of phosphorus were applied to designated plots at the rate of 600 pounds per acre of an 0–14–14 fertilizer. Potash was supplied as muriate of potash, and the phosphorus sources were basic slag, phosphoric acid (85% ortho) and 20% superphosphate. Rock phosphate applied at the rate of 2,000 pounds per acre served as the fourth source of phosphorus. The calcium content of all fertilizers, except that of the rock phosphate, was balanced with high calcium limestone. Each phosphorus plot (18×21 feet) was divided into smaller subplots (18×7 feet) on which elemental sulfur was applied at acre rates of 0, 60, and 100 pounds with allowance being made for the sulfur carried by the superphosphate.

Micro-elements and magnesium in the form of chlorides were applied on all plots at acre rates equivalent to 10 pounds of $CuSO_4 \cdot 5H_2O$, 20 pounds of $MnSO_4 \cdot 4H_2O$, 10 pounds of $ZnSO_4 \cdot 7H_2O$, and 50 pounds of $MgSO_4 \cdot 7H_2O$. Borax was applied at a rate of 10 pounds per acre. The micro-elements and phosphoric acid (85% ortho) were applied in solution form while the other fertilizer ingredients were broadcast by hand.

The experimental area was sown uniformly with Pensacola Bahia grass, *Paspalum notatum* Flügge, an inoculated seed mixture of red clover, *Trifolium pratense* L., and a Florida strain of black medic clover, *Medicago lupulina* L. Due to the scarcity of rainfall and lateness of planting in January 1944, the germination and growth of clover were not satisfactory. In 1945 all plots were reseeded and fertilizer treatments, omitting lime, were applied at the same rates as in 1944.

Hand-plucked samples of red and black medic clovers were used for chemical analyses. Separate sulfur analyses were made of each clover from each of the three replicated sulfur treatments with each of the four sources of phosphorus. Composite samples of each clover from the three replicates were used for the other mineral analyses.

Plots were harvested by taking a 25-inch yield strip lengthwise through the center of each plot with a power-driven lawn mower. Plots with the largest clover growth were not cut as clean with the lawn mower as the plots with the smaller plants because the machine rode over without cutting all of the tall clover. The entire sample from each plot was oven-dried to constant weight. The clover yields were based on the estimated percentage of clover in the legume-grass mixture on each plot prior to harvesting.

RESULTS

Clover growth response to sulfur fertilization was apparent the first month following planting. The differences in growth became more pronounced with age, and at harvest time, March 15, there was a striking visible contrast between the clovers of the sulfur and no-sulfur plots. Fig. 1 shows the growth of the legume mixture with and without sulfur on the plots where basic slag was used as the source of phosphorus. The clovers had a light green color and growth was retarded on the no-sulfur plots, while the plants fertilized with sulfur had a vigorous growth and a dark green foliage (Fig. 2). In the absence of sulfur, red clover growth was more restricted than that of black medic.

The influence of sulfur on the yields of mixed plantings of red and black medic clovers fertilized with four sources of phosphorus is given in Tables 1 and 2. The differences in clover yields due to sulfur were highly significant with phosphorus sources other than superphosphate. It is recognized that seeding immediately following the surface application of insoluble materials, such as elemental sulfur and rock phosphate, is not a true test of their value. However, in this instance, the residual effects of those materials applied the previous year and their influence on the young clover growth cannot

be overlooked. The young grass and clover growth was retarded on the plots treated with 85% ortho phosphoric acid and plants were small at the first cutting, but the later growth appeared to be normal.

FIG. 1.—Growth of clover on plots fertilized with basic slag as the source of phosphorus. Left, without sulfur; right, with sulfur.

TABLE 1.—*The influence of sulfur on the dry weight yields of the total vegetation and of red and black medic clovers when applied with four sources of phosphorus, first cutting, March 15, 1945.*

Source of phosphorus	Yield in grams of grass and clover*		Yield in grams of red and black medic clovers†	
	Sulfur	No-sulfur	Sulfur	No-sulfur
Basic slag	223	92	187	10
Rock phosphate	155	92	128	5
Superphosphate	164	117	102	53
Phosphoric acid (85%)	114	79	26	3

*Mean yield (oven-dried tissue) per sample strip (25 in. × 18 ft.) of the total vegetation (grass and clover combined) harvested from center of plots of the 60 and 100 pounds per acre of sulfur and no-sulfur treatments.

†Clover yields based on percentage estimates before harvesting.

TABLE 2.—*Mean dry-weight yields in grams of red clover when sulfur was applied at 60 and 100 pounds per acre with four sources of phosphorus.**

Source of phosphorus	Sulfur		No sulfur
	60 lbs. per acre	100 lbs. per acre	
Basic slag	21	11	3
Rock phosphate	25	22	2
Superphosphate	25	13	22
Phosphoric acid	16	25	2

*Yields are means from hand plucked quadrate (2.5 × 2.5 ft.) of aftermath growth from three replicates taken May 10, 1945. Oven-dried weights.

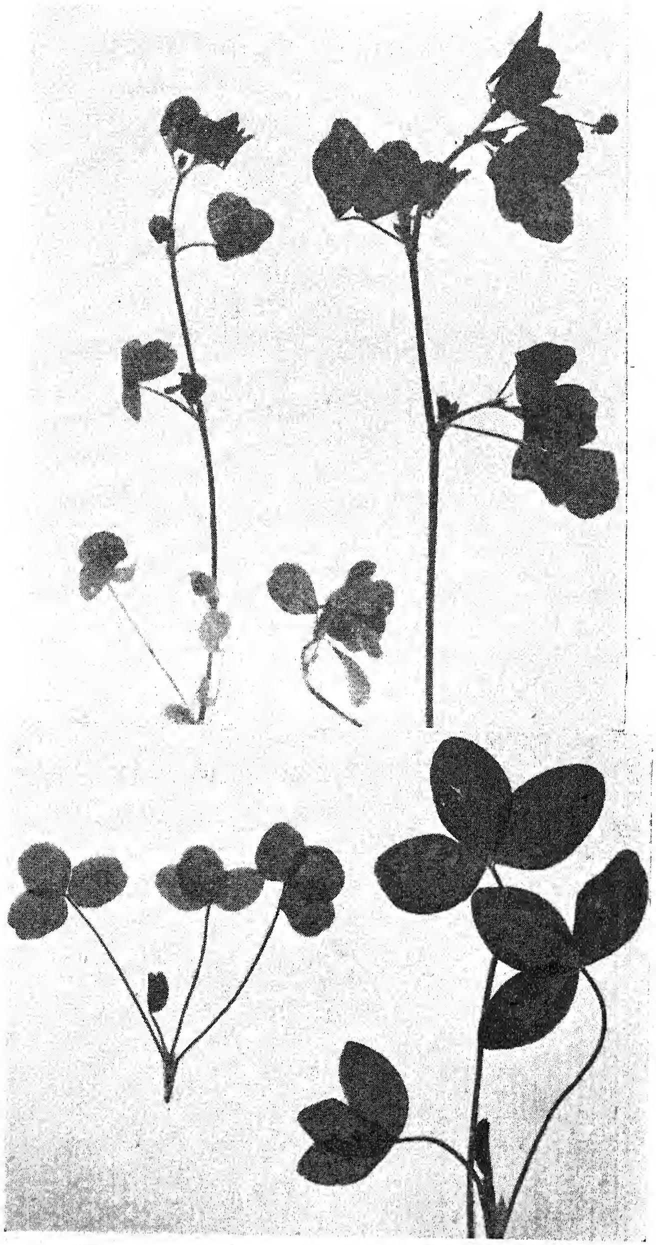

FIG. 2.—Healthy and sulfur-deficient clover plants grown on Leon fine sand. *Above*, black medic; *below*, red clover. *Left*, without sulfur; *right*, with sulfur. May 14, 1945.

Yields from the first harvest (Table 1) were low because of an extreme spring drought. However, due to the method of harvesting, the amount of clover growth on the plots treated with sulfur was greater than the reported results indicate. At that date there were no significant differences in the yields of the plots fertilized with sulfur at the rates of 60 and 100 pounds per acre, and the results given in Table 1 are the mean yields of the sulfur and no-sulfur treatments. At a later date when only the red clover was harvested by hand plucking (Table 2) there was a pronounced increase in yields in all cases where sulfur was applied, except with the superphosphate treatments.

The chemical composition of pure samples of red and black medic clovers are presented in Table 3. The increase in percentage of sulfur in the clover from the sulfur treatments is highly significant with phosphorus sources other than superphosphate. It will be noted that the nitrogen content of the sulfur-deficient plants is lower than that of healthy plants, whereas the sulfur content is, roughly, one-half that of healthy plants. With the other mineral elements the results were not consistent.

TABLE 3.—*The chemical composition (oven-dry basis) of red and black medic clovers as affected by sulfur applied with four sources of phosphorus to Leon fine sand, samples taken March 15, 1945.*

Source of phosphorus and sulfur treatment	Nitrogen, %		Phosphorus, %		Potassium, %		Calcium, %		Magnesium, %		Sulfur, %	
	Red clover	Black medic clover	Red clover	Black medic clover	Red clover	Black medic clover	Red clover	Black medic clover	Red clover	Black medic clover	Red clover	Black medic clover
Superphosphate........	3.32	2.99	0.49	0.45	2.55	2.09	2.49	2.76	0.29	0.34	0.22	0.26
Superphosphate+sulfur	4.07	3.72	0.45	0.39	2.22	1.48	2.53	2.46	0.31	0.29	0.26	0.28
Basic slag..............	—	2.91	0.25	0.26	2.32	1.50	2.69	3.83	0.31	0.34	0.14	0.12
Basic slag+sulfur........	4.82	4.24	0.33	0.37	1.87	1.74	2.34	2.13	0.34	0.30	0.24	0.25
Rock phosphate........	—	2.48	0.36	0.42	2.45	1.88	2.56	3.16	0.34	0.42	0.14	0.10
Rock phosphate+sulfur	3.47	3.87	0.43	0.42	1.88	2.05	3.16	2.23	0.42	0.29	0.24	0.24
Phosphoric acid.........	—	2.65	—	0.54	—	2.00	—	3.00	—	0.34	0.15	0.10
Phosphoric acid+sulfur	—	2.99	—	0.50	—	1.81	—	2.79	—	0.26	0.21	0.21

DISCUSSION

Recent advances in the field of animal and human nutrition have placed greater emphasis on the nutritional quality of agricultural crops. The use of biological assays, to measure feed efficiency, indicates that soil treatments bring about differences in feed other than those commonly measured by standard methods of analyses (6). It

can be expected that with a soil of such a low productive capacity in the absence of sulfur, as here reported, the sulfur treatment would give benefits in addition to those of merely increasing yields. In addition to influencing the yield and mineral composition of the clovers, it is possible that the lack of sulfur might have influenced the synthesis within the plants of other organic compounds essential in animal growth. Legumes, in general, have a low protein content when grown on sulfur-deficient soils. The total sulfur content of the sulfur-deficient clover plants was uniformly low in this experiment. The levels of the sulfur-containing amino acids were not determined. However, with such a low total sulfur content it is doubtful if the amino-acid content would be very high (5). While the exact metabolic function of the sulfur-containing amino acids in animal nutrition is only partially understood, there is some indication that these compounds might affect reproduction and other metabolic processes in animals (5, 6).

Several regions have been found in the southern states where sulfur increased the yields of cotton (2, 4, 8). The sulfur dust applied to peanuts probably also acts as a nutrient, in many instances, in addition to its fungicidal role, and may thus in part account for some of the phenomenal increased yields reported by its use in the peanut belt. Unpublished data accumulated by the Florida Agricultural Experiment Station during the past five years indicate an increase in yield and quality of tobacco with higher ratios of sulfur in the fertilizer than is usually recommended for that crop. It is generally recognized that plants with a high protein content or especially rich in organic sulfur compounds respond most markedly to the application of sulfur as a fertilizer. In this experiment clover responded very favorably while Pensacola Bahia grass displayed little, if any, response to sulfur fertilization.

The results reported support those of other workers in the South which indicate that supplements of other nutrient elements may be necessary if high-analysis fertilizers are used. Furthermore, increased yields of legumes may be expected in some rural regions if additional sulfur is used with the low rates of fertilizers commonly applied to the general farm and pasture crops in that area.

SUMMARY

A grass and clover test was established on a virgin Leon fine sand near Gainesville, Fla. The soil is typical of a large portion of the flat pine land of peninsular Florida.

Yields of red and black medic clovers were highly significantly increased when sulfur was added to fertilizers which contained basic slag, rock phosphate, and phosphoric acid (85% ortho) as the sources of phosphorus. Yields were not significantly increased when sulfur was added to fertilizers containing superphosphate (20%).

Sulfur fertilization had little influence on the growth and yield of Pensacola Bahia grass.

Clovers fertilized with sulfur had a higher nitrogen and a significantly higher percentage sulfur content.

Results indicate that the natural supply of sulfur, in the rural areas, might be insufficient for the normal growth of clovers on the virgin Leon sandy soils.

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Substitution of Sodium for Part of the Potassium in Mixed Fertilizers[1]

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At a conference of New York, New Jersey, and Pennsylvania fertilizer mixers and dealers attended by the senior author late in June 1946 one of the main problems under discussion was how to overcome the threatened shortage of potash. It appeared that the obtainable supply of potash due to regional allotments, freight car shortages, etc., would not be adequate to meet the needs of this region in 1947. There was considerable discussion of eliminating high potash ratios entirely and of reducing the potash ratio for specific crops. The suggestion was made that, as an emergency measure, sodium might be substituted for part of the potassium in mixed fertilizers, citing the work of Holt and Volk (6)[3], Hartwell and Damon (4), Harmer and Benne (3), and Sayre and Shafer (10).

A request was made for more specific data on the partial substitution of Na for K in mixed fertilizers for New York soils and crops. The experiments here reported were undertaken as an emergency measure to supply these data in time for the 1947 fertilizer program.

PLAN OF EXPERIMENT

Since potassium is an essential element for all plants, it is obvious that no other element could entirely replace it as a nutrient for any crop. However, many experiments in Europe (1, 7, 8, 9, 11, 12) and the United States (2, 3, 4, 5, 6) have indicated that sodium could be partially substituted for potassium as a cation in the plant metabolism or structure. This partial replacement of potassium by sodium might be greater where the supply of potassium available to the plant is very limited, and conversely the replacement might be less or not take place at all where the supply of potassium available to the plant is abundant.

Accordingly, for this experiment, four levels of potassium were supplied to the crops in a factorial design with four replications of each treatment for each crop. The levels of potassium supplied in the form of 60% muriate of potash were as follows in terms of K_2O per acre: 50 pounds, 100 pounds, 150 pounds, and 200 pounds.

The sodium levels were as follows: (a) At each potash level one-fourth of the potassium was replaced by the molecular equivalent amount of sodium in the form of sodium chloride. (b) At each level one-fourth of the potassium was replaced by three times the molecular equivalent amount of sodium. Consequently this level received equal amounts of sodium and potassium on a molecular basis. This second level of sodium was included because Pfeiffer, Rippel, and Pfetenhauer (9) reported that sodium could replace potassium in the ratio of 0.25:1 in small concentrations and in the ratio of 0.38 to 1 in relatively large concentrations. (c) Also at each level one-fourth of the potassium was replaced by 500 pounds of sodium chloride per acre. This was an arbitrary amount decided upon because 4 years' experiments (13) in this region had indicated that this was the optimum amount of sodium chloride as a fertilizer for beets. (d) At each potash level there was also a no-sodium treatment.

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[2]Head of Division and Assistant Professor, respectively. Dr. J. I. Shafer, Jr., formerly of this Division, assisted in designing the treatments and randomized plot arrangement.

[3]Figures in parenthesis refer to "Literature Cited", p. 160.

In addition to the 16 treatments in this factorial design there were two other treatments, namely, (a) no potassium and no sodium; and (b) no potassium with 500 pounds of sodium chloride. With four replications this made 72 plots for each crop.

The fertilized area of each plot was 22 feet a long the rows and 20 feet across the rows. In harvesting, a 2-foot strip between plots in the row was discarded to eliminate border effect, and only the center 8 feet (four interior rows) of beets and center 10 feet of soybeans on each plot were harvested for the records.

Nitrogen at the rate of 100 pounds of N per acre in the form of sulfate of ammonia and phosphoric acid at the rate of 200 pounds of P_2O_5 per acre in the form of 20% superphosphate were applied uniformly to all plots so that crop growth would not be limited by lack of either of these elements and full advantage could be taken of the heavier rate of potash application.

To be of value to growers and the fertilizer industry in overcoming the imminent shortage of potash, this experiment would have to be completed in the current growing season which was already well advanced. Therefore, the choice of crops was necessarily limited to quick-growing crops that could be planted in July. Within these limitations it was further decided to conduct the experiment with one crop known to respond profitably to the application of sodium as a fertilizer, for which canning beets was selected; and another crop on which no stimulating effects from sodium as a fertilizer had been reported. Soybeans for hay or green manure crop (Wilson variety) was selected for this category.

Harmer and Benne (3) stated that all crops could be grouped in two main classes in regard to response to sodium, as follows: (a) Those which are benefitted by sodium only when there is a deficiency of potassium. For these crops sodium apparently has no special function but merely assists in some of the functions of potassium when the supply of potassium is insufficient for the full needs of the crop. This group includes buckwheat, corn, lettuce, onion, parsley, parsnip, peppermint, potato, rye, soybeans, spinach, squash, strawberry, sunflower, and white beans. From this list the soybean was selected as best suited to the limitations of this experiment. (b) Crops which are benefitted by sodium in the presence of an ample supply of potassium. For this group sodium appears to perform definite functions in the plant metabolism which only sodium can fulfill. Crops in this group which showed the largest response to sodium are celery, mangels, sugar beets, table beets, Swiss chard, and turnips. From this group the table beet was selected for the test. Both crops for this experiment were planted on Dunkirk silt loam on July 18, 1946. The soybeans were sown with a grain drill in rows 7 inches apart. The beets (Detroit Dark Red variety) were sown with a four-row drill in rows 2 feet apart. The soil had a pH of 6.8, and it was low in available nitrogen, phosphorus, and potassium. It had a very high phosphorus fixation capacity.

The soybeans were harvested with a mowing machine Oct. 2, 1946, and were weighed immediately. The average green weights from each fertilizer treatment are given in Tables 1 and 3, and are graphically illustrated in Fig. 2. The beets were harvested and topped by hand on October 23. The average weights of topped beets from each treatment are given in Tables 1 and 2, and are shown graphically in Fig. 1.

DISCUSSION OF RESULTS

The responses of the two crops to the fertilizer treatments were in striking contrast, as shown in Table 1 and Figs. 1 and 2. With beets, 500 pounds of NaCl per acre without K_2O (treatment R) produced a significantly larger yield than any of the four levels of potassium fertilization without sodium. With soybeans, however, this treatment produced the lowest yield of the entire series. Apparently, the soil was better able to supply the needs of the beets for potassium than for sodium, but was not able to supply adequately the needs of the soybeans for potassium.

TABLE 1.—*Effect of partial substitution of potassium by sodium at various levels in mixed fertilizers, 1946.*

Treatment in lbs. per acre*			Yield of beets		Yield of soybean hay (green weight)	
Code	K_2O	NaCl	Tons per acre	Rank	Tons per acre	Rank
A	50	0	8.83	15	5.32	6
B	37½	15½	8.46	17	5.24	8
C	37½	46½	8.50	16	5.30	7
D	37½	500	11.84	2	4.52	14
E	100	0	8.90	14	4.84	12
F	75	31	9.31	13	5.01	11
G	75	93	10.64	8	5.07	10
H	75	500	12.89	1	4.75	13
I	150	0	9.60	11	6.42	1
J	112½	46½	10.40	10	5.38	5
K	112½	139½	10.58	9	5.10	9
L	112½	500	11.66	3	4.12	16
M	200	0	9.44	12	5.67	3
N	150	62	11.32	4	5.64	4
O	150	186	11.06	7	5.76	2
P	150	500	11.21	5	3.75	17
Q	0	0	7.00	18	4.18	15
R	0	500	11.11	6	3.43	18
Least significant difference at 5% level....			1.24		0.67	
Least significant difference at 1% level....			1.65		0.90	

*In addition, all plots received a basic fertilizer application of 100 pounds per acre of N in the form of sulfate of ammonia and 200 pounds of P_2O_5 in the form of 20% superphosphate. 60% KCl was the source of K_2O.

BEETS

With beets, the largest yield without sodium was from treatment I (150 pounds of K_2O), but there was no significant difference in yields even at the 5% level between the four levels of potassium fertilization without sodium. Where one fourth of the K_2O at each level was replaced with an equivalent amount of Na, there was a progressive and almost straight-line increase in yield with each increasing increment, treatments B, F, J, and N. The differences between each successive level in this series were not significant, but the differences in jumps of two levels in this series were significant at the 1% level throughout.

Harmer and Benne (2) showed that on a muck soil very deficient in potash, sodium chloride without potash failed to give satisfactory yields of any crop and resulted in unhealthy growth of each crop, proving that sodium cannot completely replace potassium as a soil amendment. Although the beets in the experiment herein reported made a better growth without added potash than without sodium chloride, the upland silt loam soil in which they were grown was not

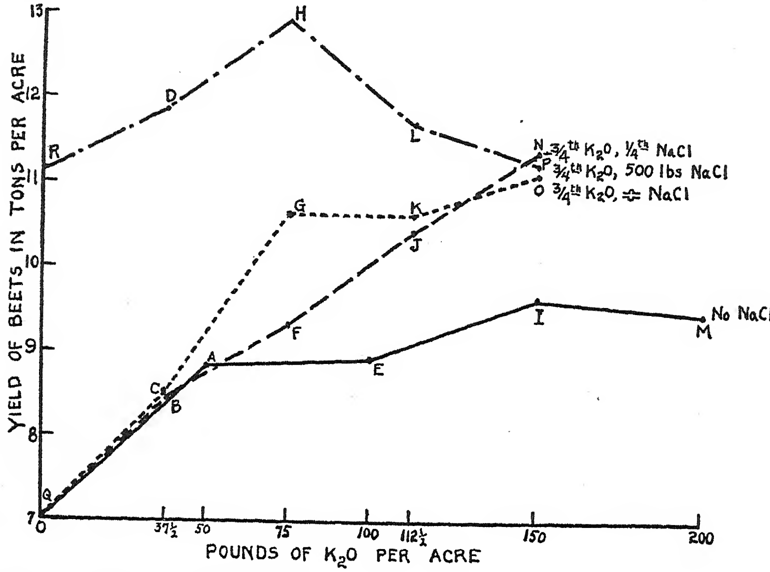

FIG. 1.—Yields of beets as influenced by four levels of potassium and by the replacement of one-fourth of the potash at each level by different levels of sodium chloride. Letters (A to R) refer to fertilizer treatments in Table 1.

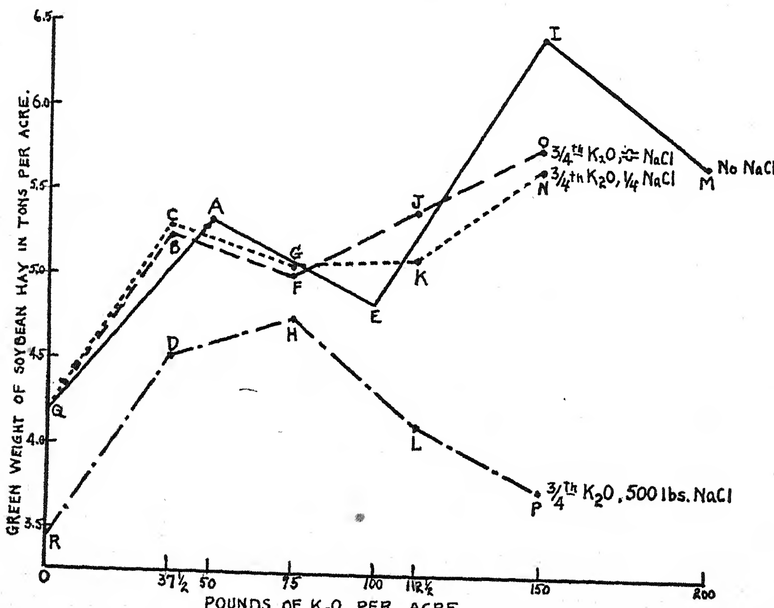

FIG. 2.—Yields of soybean hay as influenced by four levels of potassium and by the replacement of one-fourth of the potash at each level by different levels of sodium chloride. Letters (A to R) refer to fertilizer treatments in Table 1.

severely deficient in available potash. Consequently, the results and conclusions are not at variance with those reported by Harmer and Benne.

Where one-fourth of the K_2O at each level was replaced with three times the equivalent amount of sodium, thus making an equal application of K and Na, there were significant and progressive increases in yields up to the second potash level (75 pounds of K_2O, treatment G), but above this level of K_2O there was no appreciable difference in yield.

With the highest application of sodium (500 pounds NaCl), only the second potash level (75 pounds K_2O, treatment H) produced a significant gain over no potash (treatment R). The two higher levels of potash with 500 pounds of NaCl resulted in progressive decreases in yields of beets. Possibly the increasing amounts of soluble salts at these levels reached the point of slight toxicity due to plasmolysis or possibly the high proportion of Na and K may have upset the balance of the other cations in the metabolism of the plant. Whatever the cause, a similar effect was produced on the soybeans.

The highest yield of beets was obtained from 75 pounds of K_2O with 500 pounds of NaCl (treatment H), but this yield was not significantly better than treatment D (37½ pounds of K_2O and 500 pounds of NaCl) which would make the latter appear to be a more economical treatment. However, the H treatment was the only treatment containing potash plus 500 pounds of NaCl that was significantly better than 500 pounds of NaCl without any potash, treatment R. Therefore, the H treatment must be considered the most desirable ratio of potash and sodium. The factorial analysis also clearly indicates that this is the best treatment in the beet experiment.

At four of the potash levels, 37½, 75, 112½, and 150 pounds of K_2O per acre, there were also three levels of sodium chloride at each potash level. At each of these potash levels there was no reduction in yield of beets where one-fourth of the K_2O had been replaced with any of the levels of Na.

The first 16 treatments given in Table 1 form a 4×4 factorial experiment, with four levels of sodium at each of four levels of potassium. Considering only this factorial portion of the experiment,

TABLE 2.—*The influence of increasing increments of potassium and sodium on the yield of canning beets in tons per acre.*

Pounds of K_2O per acre	Sodium levels				Average
	0	One-fourth of K replaced by Na	Na equivalent to three-fourths of K	500 lbs. of NaCl per acre	
50	8.83	8.46	8.50	11.84	9.41
100	8.90	9.31	10.64	12.89	10.43
150	9.60	10.40	10.58	11.66	10.56
200	9.44	11.32	11.06	11.21	10.76
Average	9.19	9.88	10.20	11.90	

Least significant difference between individual treatments = 1.69
Least significant difference between Na levels or between K levels = 0.85

interesting information is obtained on the effects of varying levels of potassium and sodium on beet yields. The yields of these first 16 treatments, therefore, have been rearranged in Table 2 which also shows the average yields obtained at each sodium and potassium level.

The most interesting feature of these data is the highly significant response of the beets to increasing levels of sodium; and the also highly significant response to the second increment of potash. From these data we would conclude that the optimum fertilizer recommendation for beets is 75 pounds of K_2O and 500 pounds of salt per acre.

The highly significant interaction between K and Na levels is best demonstrated by comparing the response to increasing amounts of sodium at the 100-pound level of K_2O with the same at the 200-pound level. There is a very definite differential response shown by the reduced yields at the higher rate.

SOYBEANS

The soybean yields are given in Table 1 and are graphically shown in Fig. 2. The outstanding features of this experiment were the marked response of the soybeans to potash and their apparent low tolerance of NaCl. Treatment R (500 pounds of NaCl without any K_2O) produced the lowest yield of the entire series and was significantly lower than treatment Q (no NaCl and no K_2O). The highest soybean yield was obtained from 150 pounds of K_2O with no NaCl (treatment I). In striking contrast the next to the lowest yield was obtained from this same amount of K_2O to which 500 pounds of NaCl was added (treatment P). These wide differences are graphically shown in Fig. 2.

At each potash level the substitution of 500 pounds of NaCl for one-fourth of the K_2O resulted in a significantly reduced yield except at the second potash level where treatment E (100 pounds of K_2O) seemed out of line with the general trend and was abnormally low in relation to the other potash treatments.

At the lowest potash level (50 pounds of K_2O) there was practically no difference in yield from the potash without sodium (treatment A) and from treatments B and C where one-fourth of the potash was replaced by an equivalent amount of Na and by three times as much Na, respectively.

Again at the second potash level (100 pounds of K_2O) there was no significant difference in yield where any of the three sodium levels replaced one-fourth of the potash in the fertilizer, but in this series the potash alone (treatment E) seemed abnormally low. In fact this whole group of treatments at this potash level was lower than the series at the first potash level with one exception. Fortunately, two higher levels of potash fertilization were included in this experiment and produced higher yields, or we might have erroneously concluded that the second potash level was beyond the point of increasing yields.

At the third potash level the highest yield in the entire soybean experiment was obtained from the 150 pounds of K_2O without any sodium (treatment I). This treatment was significantly better at the 1% level than treatments J, K, and L in which one-fourth of the K_2O was replaced by the three salt levels. Furthermore, treatments O, N,

and P contained the same amount of potash as treatment I plus three levels of NaCl respectively. That the soybeans did not require sodium if potassium was adequately supplied is shown by the significantly reduced yields where 150 pounds of K_2O were supplemented by NaCl at the rates of 62, 186, and 500 pounds in treatments N, O, and P, respectively. At the highest level of sodium and potassium, the yield was sharply reduced. Possibly this was due to a concentration of soluble salts that was slightly toxic to the soybeans, or possibly the high ratio of Na and K may have inhibited the uptake, and thus upset the balance, of the other cations in the metabolism of the plant. Apparently 150 pounds of K_2O per acre was the limit of increasing yields from increasing increments of potash for there was a significantly lower yield from 200 pounds of K_2O, treatment M.

The yields of the first 16 soybean treatments have been rearranged in a factorial design (Table 3) to show the average yields at each level of sodium and potassium.

TABLE 3.—*The influence of increasing increments of potassium and sodium on the yields of green soybean hay in tons per acre.*

Pounds of K_2O per acre	Sodium levels				Average
	0	One-fourth of K replaced by Na	Na equivalent to three-fourths of K	500 lbs. of NaCl per acre	
50	5.32	5.24	5.30	4.52	5.09
100	4.84	5.01	5.07	4.75	4.92
150	6.42	5.38	5.10	4.12	5.25
200	5.67	5.64	5.79	3.75	5.20
Average	5.56	5.32	5.30	4.29	

Least significant difference between individual treatments = 0.92 ton
Least significant difference between sodium levels = 0.46 ton.

Here again there is a highly significant difference between sodium levels, but in a negative direction. The obvious conclusion is that NaCl is very detrimental to the growth of soybeans.

Although the 150- and 200-pound levels of potash gave higher average yields than the 50- and 100-pound levels, the differences are not significant. Perhaps this lack of response is due to the late planting of the beans which reduced yields and therefore the potash requirements.

Again there is a highly significant interaction between the K and Na levels, as is evidenced by comparing the effect of various sodium treatments at the 100-pound level of K_2O with the similar treatments at 150 pounds of K_2O.

The results with both crops agree with the conclusions of Lehr (8) in a comprehensive review of the importance of sodium for plant nutrition. He states that, "Sodium cannot of course be considered as important as potassium because of the greater physiological value of the latter, but in numerous instances sodium can be applied to advantage. The importance of potassium and sodium changes with different crops." He further states, "The importance of sodium refers

chiefly to its functions *in the plant*, whether this function concerns exclusively replacement of potassium, for which an equivalent replacement is only possible in part", or whether there is a certain independent function of sodium.

CONCLUSIONS

The two crops gave strikingly different responses to the various potassium and sodium levels. The crop yields indicated that NaCl may be substituted for a portion of the potash in mixed fertilizers where the supply of potash is inadequate for the maximum growth of either crop; but, where an adequate amount of potash can be supplied, the substitution of sodium for part of the potash will not give as large yields of soybeans.

For beets, at all potash levels the substitution of NaCl for one-fourth of the K_2O resulted in no reduction in yield and in most cases significantly increased the yield, proving that for this crop the partial substitution of sodium for potassium would be a profitable practice. A relatively low level of potash and high level of sodium (75 pounds of K_2O and 500 pounds of NaCl) gave the best results with beets. For beets, which require sodium *per se*, NaCl should be considered more as an important ingredient of the fertilizer mixture rather than as a substitute for part of the potash.

With soybeans the substitution of sodium for one-fourth of the K_2O did not reduce the yield at the two lower levels (50 and 100 pounds of K_2O) and these levels were below the needs of the crop. At the third level (150 pounds of K_2O), which gave the largest yield of soybeans, the substitution of NaCl for one-fourth of the K_2O significantly reduced the yield. For soybeans a relatively high level of potash (150 pounds of K_2O) with no sodium gave the best results.

Hartwell and Damon (4) stated prophetically 27 years ago, "The gains in yield due to sodium assume unusual economic interest. In the future, conditions may be such that attention should be given to the use of our liberal supply of sodium salts as economic supplements to the limited amount of potassium."

That statement might well be applied in 1947 to certain specific crops, such as beets, if the supply of potash is not ample to meet all requirements.

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Notes

THE BEE, *CALLIOPSIS ANDRENIFORMIS*, AS A FACTOR IN ALFALFA SEED SETTING[1]

CROSS pollination of alfalfa has come to be recognized as one of the important factors involved in alfalfa seed production. Wild bees are the most efficient pollinators, but in areas long under cultivation they are often not present in sufficient numbers to provide adequate pollination. In connection with alfalfa breeding work at Lincoln, Neb., Tysdal[2] noted that a certain small bee was very abundant in alfalfa nurseries and that it was particularly active in tripping alfalfa blossoms. He reported that very good seed production was obtained on experimental plantings chiefly as a result of the favorable activity of this bee, which was identified by the Department of Entomology as *Calliopsis andreniformis* Smith and later verified by the Division of Insect Identification of the U. S. Bureau of Entomology and Plant Quarantine. In view of its apparent importance in the pollination of alfalfa, some field data concerning it were obtained at Lincoln during the seasons of 1944 and 1945.

Calliopsis andreniformis was described in 1853 by Smith[3], who gave its habitat as east Florida. Britton[4] records it from Connecticut and

[1]Contribution from the Departments of Entomology and Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Neb., and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating. Published with the approval of the director of the Nebraska Agricultural Experiment Station as Journal Series Paper No. 401.

[2]TYSDAL, H. M. Annual report on alfalfa investigations, Lincoln, Nebraska. Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering and Nebraska Agricultural Experiment Station cooperating. Unpublished. 1942.

[3]SMITH, F. Catalogue of Hymenopterus insects in the collection of the British Museum. Part I. *Andrenidae* and *Apidae*. 1853. Pages 128–129.

[4]BRITTON, W. E. Guide to the insects of Connecticut. Part III. The Hymenoptera or Wasp-like Insects of Connecticut. 1916. (Page 722.)

Maine. In 1937 Ainslie[5] published some biological notes based on observations made at Sioux City, Iowa, and in this article he stated that *C. andreniformis* "inhabits much, if not all, of the eastern area of the U. S." The Nebraska collection contains specimens of *C. andreniformis* taken at Lincoln, West Point, and Weeping Water and identified by M. H. Swenk. This bee probably occurs more widely in the state than these records indicate, although it has not been observed in the western part.

Plants visited.—Ainslee states that adults of *C. andreniformis* were collected by sweeping "hop clover while in bloom." Britton reported that it had been taken on *Solidago juncea*. The Nebraska collection includes specimens taken on *Melilotus alba*, *Medicago sativa*, *Petalostemum candidum*, *Symphoricarpos* sp., native *Rosa* sp., and *Prunus melanocarpa*. Observations indicate that alfalfa provides an attractive source of pollen for this bee. Adults were found on alfalfa blossoms in greater numbers than on several other plants in flower at the same time. Their nests occurred in greatest numbers in and near alfalfa plantings, and microscopical examination of pollen balls from burrows in the vicinity of alfalfa in bloom indicated that approximately 50% of the pollen stored consisted of alfalfa pollen. In 1945 adults were not observed until after experimental nurseries of alfalfa were in full bloom. Most early flowers stripped but later an excellent seed crop was obtained due largely to the beneficial activity of this insect.

Seasonal history.—Like all panurgine bees, it nests in burrows and spends the winter as a larva. The first adults were observed at Lincoln on June 15 in 1944 and on June 23 in 1945. Maximum numbers were present in late June and the first half of July, although considerable numbers were present until the latter part of July. Soon after the adults appeared, they began burrowing and provisioning these burrows with pollen for larval food. A series of burrows were excavated at intervals through the season in order to follow development of the immature stages. The first larvae were found on July 7 at which time they were one-fourth to one-third mature. On September 26 and November 22, the latest dates on which excavations were made in the field, larvae were present in abundance, but no pupae.

Field excavations were made on April 10 of the succeeding spring at which time only larvae were present. By the middle of June practically all had pupated. Adults were first collected on June 23. It should be mentioned that the spring of 1945 was characterized by prolonged cool, wet weather which no doubt retarded development considerably.

Burrowing habits.—Hard ground and scanty vegetation, such as field roads and paths, are favorite nesting sites. Areas in alfalfa fields with relatively thin stands were used extensively for nesting, whereas no burrows were found in solid stands of alfalfa.

The burrows were 3 to 4 inches in depth and about one-eight inch in diameter. Extending from the main tunnel, there were three to

[5]AINSLIE, C. N. Notes on the biology of two panurgine bees. Can. Ent., 69:97–99. 1937.

eight side branches one-fourth to one inch in length, each having a cell at the end where the pollen ball which served as food for the larvae was placed. Late in the season many of the cells containing larvae were infested with mites. Samples of these were collected and submitted to the Division of Insect Identification, U. S. Bureau of Entomology and Plant Quarantine. Three species were determined, *Pediculoides americanus* (Banks) and *Tyrophagus* sp., by E. W. Baker, and *Lohmannia* spp. by Henry E. Ewing.

These observations indicate the possibility of encouraging an increase of *C. andreniformis* by providing favorable nesting sites in the form of small, bare, packed to semi-packed areas at intervals in the field. The possibility of maintaining such areas with herbicides and very shallow tillage is being investigated. This bee works alfalfa flowers more slowly than *Megachile* spp. and must be present in large numbers to be very effective. The fact that adults are present for a relatively short time—late June and July—limits their effectiveness since their utilization in pollination would necessitate regulation of the flowering time of alfalfa or other plants involved to coincide with the short period of adult activity. This has not been difficult with alfalfa breeding nurseries at Lincoln, Neb., since the crop blooms over a relatively long period. For several seasons successful seed production has been the result of their intense activity for a short time in early summer.—BLISS H. CRANDALL and H. D. TATE, *Nebraska Agricultural Experiment Station, Lincoln, Neb.*

STRAIN DIFFERENCES IN TOLERANCE TO 2,4-D IN CREEPING BENT GRASSES[1]

WHILE the toxic effects of 2,4-D on bent grass have been both recognized and described,[2] differential strain responses to 2,4-D injury have not been so widely apparent.

The extent to which 66 different creeping bent grasses might tolerate 2,4-D was measured in the turf nurseries of the Purdue Agricultural Experiment Station during the summer of 1946. The herbicide was applied to duplicated small plots (3×4 feet) started from stolons in April and kept clipped at fairway height. Applications of 1,000 p.p.m. of the sodium salt of 2,4-D in 5 gallons of water per 1,000 sq. ft. of turf were applied twice after the turf was well established. The first application was made on July 31 and the second on August 26. Although the rate of application was approximately twice that ordinarily recommended, it was felt that at the higher concentration high tolerance to the chemical would possibly be more apparent. A third application, although planned, was considered unnecessary. Readings of extent of injury were made on August 14 and again on August 30, and the extent of survival, based on percentage of live stolons, was recorded on October 16. All readings were by the index system where 1 represented no injury and 10 complete destruction.

[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Ind. The work was supported in part by a grant from the Midwest Regional Turf Foundation, Inc.

[2]MITCHELL, JOHN W., and MARTH, PAUL C. Effects of 2,4 dichlorophenoxyacetic acid on the growth of grass plants. Bot. Gaz., 107:276–284. 1945.

Analyses of the data showed that differences in degree of injury among strains were highly significant. This is hardly surprising, since even with the first application of 2,4-D a wide range of tolerance to 2,4-D injury was displayed. The extent of this range and the behavior of strains after the second application are shown in Table 1, which presents the data obtained with 17 of the 66 strains included in the test.

TABLE 1.—*2,4-D tolerance indices of certain bent grasses.**

Strain	Date of rating		
	Aug. 14	Aug. 30	Sept. 16
C 34	6	5	4
C 50	6	5	3
Arlington	3	3	3
Congressional	4	4	4
Norbeck	2	1	2
C 7	1	2	2
C 21	1	2	2
Old Washington	2	2	3
Old Metropolitan	4	5	5
Old Orchard	3	4	4
C 38	1	4	7
C 62	3	3	6
C 64	4	5	6
Toronto	6	5	7
Elk 12	5	5	8
Beverly 3A	7	7	8
C 90	7	7	9

*Data from duplicated plots, 3×4 feet. 2,4-D applied as sodium salt at rate of 1,000 p.p.m. in 5 gallons water per 1,000 sq. ft. of turf. 2,4-D spray applied July 31 and August 26, 1946. 1 = no injury; 10 = complete destruction.

Conspicuous differences in strain reaction to 2,4-D injury were strikingly similar in duplicated plots. In general, strain behavior was manifest in one or another of the following patterns:

1. Injury slight—C7, C21, Old Washington, Norbeck, Arlington
2. Injury marked with some stolon mortality—Old Metropolitan, C64, Congressional, Old Orchard
3. Injury severe, with considerable stolon mortality—Beverly 3A, C90, Toronto
4. Injury marked, but some recovery evident October 16—C34, C50
5. Injury severe, with stolons displaying no recovery on October 16—C64, Toronto, Elk12
6. Injury not marked after first application, but becoming progressively more evident after second application—C38, C62

In the bent grass strains which were severely injured by 2,4-D as applied in these tests, a large percentage of stolons were killed. Living stolons bore leaves which displayed a high degree of yellowing. Strains more tolerant were less discolored, mortality was far less in evidence, and recovery was generally more rapid. The more tolerant strains in both replications showed only slight yellowing, with stolon mortality,

if any, being insignificant. Most such strains either recovered quickly from the effects of 2,4-D toxicity or, at least, they did not demonstrate more exaggerated symptoms after the second application.

It was concluded that bent grass strains vary considerably in their tolerance to injury by 2,4-D.—H. R. ALBRECHT, *Purdue University Agricultural Experiment Station, Lafayette, Ind.*

THIAZOL YELLOW FOR DETERMINING THE MAGNESIUM CONTENT OF SOIL EXTRACTS[1]

TITAN yellow has long been the standard indicator for determining the Mg content of soil extracts in quick-test procedures.[2] The shortage of the German-made form of this dye, which exhibits superior selectivity to that produced in the United States, has been responsible in part for the search undertaken by this laboratory for a substitute that would be at least equal to the best Titan yellow. Some 130 organic compounds, including all available samples of Titan yellow, were included in the study.[3] Of these, the best by far was Thiazol yellow (sodium 2-2 disulfonate of methylbenzolthiazole (General Aniline Works, Renselaer, N. Y.). It is the purpose of this note to draw the attention of soil chemists to the usefulness of this dye.

The sensitivity of Thiazol yellow in comparison with that of Titan yellow is indicated by the following data:

Dye	Visual sensitivity range, ppm Mg
Thiazol yellow (General Aniline Works)	0–30
Titan yellow (Dr. Grübler & Co., Germany)	0–15
Titan yellow (Eastman Kodak Co., P-4454)	0–10
Titan yellow (Eimer & Amend, B 37)	0–8
Clayton yellow (Eastman Kodak Co., 1770)	0–5

The broader sensitivity range of Thiazol yellow simplifies the determination of Mg in soil extracts in that at ranges greater than 10 ppm it is not necessary to substitute p-nitrobenzeneazoresorcinol for the Thiazol yellow or to resort to smaller test aliquots as is customary when Titan yellow is employed.

Table 1 illustrates the accuracy of the Thiazol-yellow test in comparison with that of the commercial preparations of Titan yellow and Clayton yellow when applied to a synthetic soil extract prepared by adding the necessary cations to Morgan's universal soil extract (buf-

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[1]Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University, Department of Soils, New Brunswick, N. J. Acknowledgement is due Mr. David D. Long, Chief of Feed and Fertilizer Research, International Minerals and Chemical Co., for his encouragement of this work and to the Company for partially financing the project.

[2]MORGAN, M. F. Chemical soil diagnosis by the Universal Soil-Testing System. Conn. Agr. Exp. Sta. Bul. 450. 1941.

PEECH, M., and ENGLISH, L. Rapid microchemical soil tests. Soil Sci., 57: 167–195. 1944.

[3]Begun by Miryam Zimmerman of this Department.

fered at 4.8 pH). The synthetic soil extracts contained 25.0, 10.0, and 2.5 ppm Mg, respectively.

TABLE 1.—*Comparative recoveries of Mg in p.p.m. from three synthetic soil extracts.*

Dye	Extract 1	Extract 2	Extract 3
Thiazol yellow (General Aniline Works)....	25	10	2.5
Titan yellow (Dr. Grübler, Germany)......	17*	8	2.0
Titan yellow (Eastman Kodak Co., P-4454)	15*	5	2.0
Titan yellow (Eimer & Amend, B 37)......	15*	5	2.0
Clayton yellow (Eastman Kodak Co., 1770)	15*	10*	2.5

*Approximate values since the concentration exceeded the sensitivity range of the dyes.

The color changes with Thiazol yellow (pale orange to rose or scarlet) are very sharp and clear-cut and they are much easier to distinguish than those of the other dyes. The two batches of Thiazol yellow that have been tested were almost identical in their sensitivity ranges.

The preparation of the dye solution consists merely in dissolving 0.1 gram of the dye in 100 ml of water. Three drops of the solution are added to the soil extract, following the use of the compensating solution as employed in the Peech procedure. In the presence of calcium concentrations exceeding 100 times that of magnesium, the colored lake that is formed between the $Mg(OH)_2$ and the thiazol yellow cannot be read accurately because of a turbidity in the test solution. This can be overcome by the use of a smaller aliquot of the solution to be tested and by diluting to the proper volume by the addition of more of the extracting solution.

An effort is now being made to develop a quick-test colorimetric method for estimating Mg in plant tissue extracts. Considerable progress has already been made by using this new dye in conjunction with suitable masking reagents.—DUANE S. MIKKELSEN and STEPHEN J. TOTH, *New Jersey Agricultural Station, New Brunswick, N. J.*

Book Review

pH AND PLANTS

By James Small, New York: D. Van Nostrand Company, Inc. VII+216 pages, illus. 1946. $4.

ALL those having to deal with the relation of pH to plant growth, plant metabolism, plant diseases, and soils as a culture medium for plants will welcome this little treatise. It deals with a field that lacks coverage of the type here given. The scope of the book is well expressed by the chapter headings which follow: The pH Scale; Buffers; Carbon Dioxide Effects; pH and Plant Sap; pH and Cell-walls; pH and Protoplast; pH and Plant Enzymes; pH and Aquatic Life; Soil pH and Plants; pH and Plant Pathology; pH and Succulents; pH and Cytoplasmic Life.

A select but nevertheless rather extensive bibliography, referred to frequently in the text, should be of considerable help and convenience to workers in this field.—E. TRUOG.

Agronomic Affairs

RESULTS OF BALLOTING ON THE EXPANDED PROGRAM

IN ACCORDANCE with the action taken at the business meeting of the Society held on November 21 at Omaha, Neb., the recommendations of the committees on Policy and Program and Revision of the Constitution and By-Laws, as presented below, were submitted to the membership for mail vote. Fourteen hundred and ninety-one ballots were sent out in early December, 1,339 to members in this country and 152 to members in other countries. By January 15, the date set for the counting of the ballots, a total of 765 members had returned ballots. The results of the balloting were as follows:

A. Proposals of the Committee on Program and Policy:

Proposal No.	Number of Votes For	Number of Votes Against
1	745	9
2	705	47
3	596	153
4	655	97
5	734	19
6	700	54
7	670	77

B. Proposed Amendments to Constitution:

Amendment No.	Number of Votes For	Number of Votes Against
1	730	18
2	730	18
3	730	17
4	722	25

There were 534 who favored all proposals and 6 who were opposed to all proposals. Seven hundred and seven favored all the amendments and 10 were opposed to all amendments. The other members voting favored some proposals and amendments and were opposed to others.

The Executive Committee is pleased with the large mail vote, for it is a manifestation of general interest in the Society's activities. Moreover, the Executive Committee interprets the overwhelming vote in favor of the proposals and amendments as evidence that the proposed program can be undertaken with assurance of its success.

The first major step in the development of the expanded program is obviously the raising of the Developmental Fund in accordance with Proposal No. 7 of the Committee's report. A national committee under the chairmanship of Professor Emil Truog is helping in the organization of state committees and is proceeding with this all-important job. This committee will need your active support and will welcome your suggestions. It is important that the development

fund be raised rather quickly, for progress on other phases of the program depends upon it.

Committees have also been authorized by the Executive Committee to work on the following aspects of the expanded program:

1. New Magazine and Establishment of Permanent Headquarters
2. Regional, State, and Local Branches
3. Program on Agronomic Education
4. Program on Agronomic Applications

The personnel of these committees and announcement of some of their plans will appear in the next issue of the JOURNAL.

The officers of the Society fully recognize the size of the job that lies ahead. With such support by the members as has already been manifested, however, we believe that rapid progress can be made toward our goal—a broader and more vigorous program for the Society. We earnestly solicit your continued and active support.—W. H. PIERRE, *President*.

REPORT OF THE COMMITTEE ON POLICY AND PROGRAM OF THE AMERICAN SOCIETY OF AGRONOMY AS APPROVED BY MAIL BALLOT

THE first report of the Committee on Policy and Program was published in the February 1946 issue of the JOURNAL of the Society and was presented at the meetings held in Columbus, Ohio, February 26–March 1, 1946. The report carried eight specific recommendations and each of these was discussed separately at the meeting. For the information and guidance of the Committee a show of hands was requested after the discussion of each of the eight recommendations. Both the discussion and show of hands indicated a keen interest by the membership in the proposals for strengthening and expanding the Society's program. Because of the fundamental nature of the recommendations, and the fact that most members had not had the opportunity of studying the report before the meetings, it was not submitted for vote by the membership of the Society.

Since the meetings in Columbus, the committee has given further study to the strengthening of the Society's program. A letter was sent to all members of the Society in early May expanding on some sections of the report and inviting additional suggestions for its revision. A total of over 70 replies was received, a number of which expressed the views of groups of members.

On August 19, the Committee met in Chicago for the purpose of reviewing the suggestions received, considering certain subcommittee reports and making such modifications and additions to the original report as seemed desirable.

In submitting this revised report, the Committee wishes first of all to re-emphasize its conviction that the Society needs to develop a more extensive and vigorous program. We believe this to be imperative if the Society is to increase its effectiveness and usefulness to the membership and to the profession, and if it is to secure greater public recognition and support of agronomic programs.

While the Society has served reasonably well those of its members who are engaged primarily in research, it has not adequately met the needs of many members who are primarily interested in the interpretation, dissemination, and application of research. Neither has it served the large number of men trained in Agronomy not now members of the Society,—men with a professional interest in the field, who are interpreting and applying the results of agronomic research and who need the help that can be provided by a professional Society. Article II of the Society's constitution reads: "The object of the Society shall be the increase and dissemination of knowledge concerning soils and crops and the conditions affecting them."

It is the firm belief of the Committee that the time is most opportune for the initiation of an expanded program. Never before has there been so general a recognition of the importance to the national economy of efficient and sustained agricultural production. Nor has public attention ever been more intently focused on the potentialities of research and the importance of "putting science to work". More foreign students are coming to this country for advanced training than ever before. The need for more and better trained men in Agronomy is urgent. Teaching standards must be maintained and increased, and promising students encouraged to major in agronomic fields.

It is on the basis of these convictions that the committee presents the following recommendations for the initiation of an enlarged program:—

1. That the term "Division" be used for primary groups within the Society, that subdivisions of these major groups be known as "Sections", and that regional, state, and local units of the Society be known as "Branches".

Considerable confusion has resulted from the use of the term "Section" for the two organic groups in the Society and also for units within one of these groups. The term "Section" has also been used in referring to the regional and state units of the Society.

The recommendation that the term "Division" be used to designate the major groups within the Society is in agreement with the recommendation made to and approved by the Crops Section at the Annual meeting held in Columbus last February.

Under the proposed usage, the "Soils Division" would be divided into Sections as heretofore, and the "Crops Division" into Sections instead of Subsections.

The use of the term "Branch" for regional, state, or local units within the Society is in conformity with the usage of the term by such national societies as the Society of American Bacteriologists.

2. That provision be made for the formation of additional Divisions in the Society.

a. That the Constitution of the Society be amended to provide a procedure for the formation of new Divisions by members of the Society.

b. That the Executive Committee appoint a special committee to organize programs on agronomic education for the 1947 and 1948 annual meetings and submit recommendations relative to a Division on Agronomic Education.

c. That the Executive Committee appoint a special committee to organize programs on topics relating to the applications of agronomic research to problems of soil and crop management for the 1947 and 1948 annual meetings and to submit recommendations regarding the formation of a new Division in that subject matter field.

There are many members of the Society whose interests are in the interpretation and application of research or in the interrelations of crop and soil research. A substantial number of this group feels that their interests and the welfare of the Society would be promoted by the formation of one or more new Divisions. Your Committee is in agreement with this viewpoint. It recognizes, however, that such changes should be made under the guidance and approval of the Executive Committee and the Council as proposed by the Committee on the Revision of the Constitution and By-Laws and that a new Division should be added only after a trial period to demonstrate the need for and interest in the proposed Division. It, therefore, recommends that the Constitution of the Society be amended to provide a procedure for the formation of additional Divisions.

The Committee has received proposals for the formation of a Division of Resident and Extension Teaching. There is no doubt that the Society can and should help in strengthening the work in the field of agronomic education. It is of special importance as undergraduate and graduate teaching is being rapidly expanded. The Committee, therefore, recommends that the Society have a special committee develop programs on symposia in the field of Agronomic Education for the next two annual meetings. The quality of the programs and the interest shown in them may indicate whether there is a need for a Division of Agronomic Education.

Members of the Society interested in fields of activity in which the results of research are applied or disseminated have urged the formation of additional Divisions to meet their needs. It is the conviction of these members that the existing Divisions do not provide programs best suited to their interests nor do they provide full opportunity for their participation in Society activities. The Committee believes that the interests of these members should be fully recognized and their requests met subject only to the provision indicated above, namely (1) a demonstration of the need for and interest in a new Division by first operating on a trial basis, and (2) formation in accordance with the suggested amendment to the Constitution. The Committee, therefore, makes recommendation 2-c.

The Committee recognizes the fact that the recommendations under this section do not fully meet the desires of the members primarily concerned with agronomic education and the applications of agronomic research. Neither is it in keeping with the thought of

those members who feel that the formation of new Divisions may not be to the best interests of the Society. We believe it offers an exploratory approach to the solution of a vital problem and that if accepted, will facilitate a final solution that will promote the welfare of the Society and its members.

3. That the Society expand its present 3-day meeting to a 4-day meeting.

In the past few years, one day of the annual meetings has been devoted to the presentation of general papers, leaving only two days for the sectional programs. This has necessitated holding as many as six sectional meetings concurrently.

The addition of one day to the annual meetings would make it possible to provide for additional sectional programs and at the same time reduce the number of programs held concurrently. Moreover, it would provide greater opportunity to hold round-table discussions, conferences, and meetings of committees.

4. That the Society publish a semi-popular magazine under some such title as "Agronomic Progress, A Magazine of Soil and Crop Management".

The committee has defined the objectives and field of the new publication as follows:

"Its audience is the increasingly large number of those who—in our highly organized system of progressive agriculture—are between the scientist and the farmer; and added to these are the also increasingly numerous farmers and farm managers with more than popular interest in new developments. Its contributors are mainly the scientists and the information workers of public research and action agencies, colleges, universities, and industries. The magazine will present authoritative material in the strictest sense."

"With scientific thoroughness but with particular attention to the laymen's regard for plain statement and practical application, "Agronomic Progress, A Magazine of Soil and Crop Management" will be the "pay-off" for those currently concerned with the results of diverse and intensive investigations, constantly being conducted in crop and soil science."

A prospectus of the new publication will be distributed at the annual meeting and will be mailed to all members in November.

The committee estimates that the publication may have a circulation of about 5000 within the first year, that with a subscription price of $3.00 and advertising revenue it would be self supporting, and ultimately would provide a source of income for the Society.

5. That the Society provide for a closer integration of regional, state, and local units with the national organization and help to strengthen and enlarge the scope of such geographical units or branches.

In the past there has been little effort on the part of the Society to encourage the formation of regional and state units. Regional

sections of the Society have for some years been organized in the Northeast, the Midwest (Corn Belt), the South, and the West, but they have not been closely affiliated with the national Society. Neither have those sections been as active as would seem desirable in providing a forum for the discussion of problems that are primarily of regional interest.

The strengthening of regional sections or "branches" would be consistent with the growing recognition of the regional character of many problems and of the need for greater regional cooperation in the solution of such problems. It would encourage a larger number of workers to attend regional meetings and participate in Society programs, particularly those workers interested in applied fields. Well organized branch meetings would provide a place for the presentation and discussion of papers of local or regional interest and of progress reports. It is anticipated that they might divert papers primarily of local interest from the programs of the national meetings. Both the national and regional organizations would benefit from closer affiliation and cooperation. The national society could help the regional branches by lending the services of its Secretary and technical assistant in maintaining active regional organizations, by sponsoring outstanding national and international speakers at regional meetings and by publishing some of the papers presented at regional meetings. The regional branches could help the national organization by fostering the objectives of the national Society, by helping to maintain an active and strong membership, by providing articles for the national publications, and by sponsoring the organization of state and local branches.

In order to help integrate the regional branches with the National Society the Committee recommends that each regional branch have a representative on the Executive Committee or Council of the Society (See proposed Amendments No. 1 and 3 of the report of Committee on Revision of the Constitution and By-Laws).

The committee recommends, further, that consideration be given to the establishment of state branches of the Society. In many states the membership probably is too small at the present time to organize and maintain active state branches. It is believed, however, that the strengthening of the program of the Society at the national and regional levels will help materially in the organization and active functioning of state and local branches.

6. That the Executive Committee of the Society be empowered to establish a permanent headquarters and to employ a full-time Executive Secretary and Treasurer, a full-time Editor, and such clerical help as is needed for the enlarged program, as soon as funds are available.

The expansion of the Society's program in accordance with the recommendations of this report would place a very heavy if not impossible burden on the officers of the Secretary-Treasurer and Editor as now constituted. The committee believes that the enlarged and expanded program will ultimately require the services of two full-

time technical men. Many useful functions would be performed by an adequately staffed and closely unified office. Not only would the staff be able to perform the necessary functions usually associated with such an office, but it would be helpful in advancing the Society's interest in such ways as the following: (1) It could help the Executive committee as well as other committees of the Society by bringing together pertinent data on the Society's problems and in studying the Society's needs. (2) It could render valuable assistance to regional and state branches of the Society in arranging meetings, developing programs, reporting on meetings, tours, and work in progress. (3) It could assume responsibility for the editing of Society monographs and in other ways promote the publication of monographs. (4) It could help in developing closer relationships with foreign scientists and scientific societies, in promoting international meetings, in facilitating the exchange of students and scientists between this and other countries, and in routing of foreign visitors.

If it should be feasible to employ only one full-time man during the initial period of reorganization, it is recommended that this be a full-time Editor whose first responsibility would be the editing of the new magazine.

The JOURNAL of the American Society of Agronomy would continue to be edited as at present. It is recommended, however, that after the initial period, the Executive Committee give consideration to the possibility of combining all editorial work in one office.

7. **That in order to finance the expanded activities of the Society a development fund of a minimum of $25,000 be raised, at least 20% of which shall be by contributions from members of the Society and the transfer of Society funds, the balance to be raised by grants-in-aid from outside sources, including educational and scientific foundations, farm organizations, and industry.**

Estimates of costs of enlarging the program were made before arriving at the above-mentioned figure. It was recognized as desirable that a sufficient fund be raised to pay all costs of expansion for at least one year, after which it was anticipated that increased returns from dues, subscriptions, and advertising would be sufficient to finance the enlarged program. These estimates were based in part on a study of the budgets of other societies having semi-popular publications, and estimates from publishers, advertising agencies and prospective advertisers.

In accordance with the Committee's belief that Society members should raise a substantial portion of the proposed fund, a canvass was made of the membership regarding prospective contributions. Of approximately 175 that replied, over 150 indicated that they would be willing to contribute to the Development Fund. (Total of $2,122.50) It is the belief of the committee that a considerable number of others will contribute when the development program has been definitely determined upon.

8. **That the foregoing recommendations of this report be submitted to a mail vote of the entire membership immediately after the Omaha meeting of the Society.**

The committee is of the opinion that the program recommended in this report is of such a nature that to be successful it would need the wholehearted support of the members of the Society. The committee urges a full discussion of the report at the November meetings. If after this discussion it seems desirable to make certain revisions or additions to the report, this will be done before it is submitted to the Society for final action.

The Committee has cooperated closely with the Committee on the Revision of the Constitution and By-Laws appointed last February by President Hughes and urges approval of the report of this Committee. The four amendments to the constitution and by-laws proposed would, if adopted, implement the recommendations of this report and provide a procedure for the greater participation of members in Society affairs.

The Committee believes that the adoption of these reports will not only strengthen the Society's program but it will enable the Society to give continued study to current problems and gradually work out needed adjustments. Among problems that need continued study are the scope of Society publications; the functioning of different divisions, sections, and branches; and the financing of society activities.

It is suggested that the report of this committee and the results of the voting be published in an early issue of the Journal. *It is further recommended that this committee be discharged, and that the executive committee appoint such committees as may be needed to implement whatever program is adopted by the Society.*

Members of the Committee

F. W. Parker	S. P. Swenson
J. D. Luckett	N. J. Volk
R. D. Lewis	Hans Jenny
Russell Coleman	Grover F. Brown
Earl Jones	H. E. Brewbaker
H. K. Wilson	J. C. Lowery
H. B. Siems	A. L. Clapp
Richard Bradfield	G. G. Pohlman, *Secretary*
I. J. Johnson	W. H. Pierre, *Chairman*

This report was submitted to the Executive Committee of the Society on October 5, 1946.

REPORT OF COMMITTEE ON REVISION OF THE CONSTITUTION AND BY-LAWS AS APPROVED BY MAIL BALLOT

THE present Constitution of the Society was adopted in 1932 (Jour. Amer. Soc. Agron., 24: 839–841, 1932) and slightly amended in 1935 (Jour. Amer. Soc. Agron., 29: 967; 1062, 1037). Since the adoption of that Constitution the Society has increased its membership 40%; the Soil Science Society of America has been organized and now constitutes the Soils Section of the Agronomy Society; and national interest in matters relating to soil and crop science and management is greater than ever before. The increased national interest is reflected in the organization of the Soil Conservation Service, the development of the conservation program of the Field Service Branch of the Department of Agriculture, the agricultural program of the Tennessee Valley Authority, the formation of new societies and the publication of new magazines in the general field of agronomy. The rapid growth of public interest and increased opportunities in agronomy and related sciences are factors that make it desirable for our Society to carefully examine its organization and program to determine if it is adequately meeting the needs of its members and of the profession. The Society's Committee on Policy and Program is making that study. In February 1946 it made several recommendations including the provision for the appointment of a Committee on the Revision of the Constitution and By-Laws.

The Committee has studied the Constitution and By-Laws of several scientific societies. Consideration has been given to the possible influence of the recommendations of the Policy and Program Committee on the future of our Society. We have naturally worked closely with that Committee and have had integrated our recommendations with theirs.

It is our opinion that the present Constitution does not provide for adequate participation of members in the affairs of the Society nor for its orderly growth. We urge, therefore that these shortcomings be corrected prior to a complete revision of the Constitution and By-Laws. Such a revision might well be postponed one to three years and should be made by another and larger committee. This report, therefore, suggests only four amendments that are designed to meet the major immediate needs of the Society.

The main objective of the proposed amendments is to promote the increased participation of members in all phases of the Society's affairs at national, regional, state, and local levels. The Committee feels this objective can be attained if the Constitution is amended to provide:

1. A closer affiliation between the national society and regional, state, and local sections or branches.

2. The formation of a large and representative Council with policy-making and other functions.

3. Greater participation of members in the nomination and election of offiers.

4. The gradual expansion of the Society organization through the formation of additional Divisions by members of the Society.

The welfare of the Society will be promoted by the development of stronger regional, state, and local sections or branches. These should be closely affiliated with the National Society. This may be accomplished by giving such sections representation on the proposed Council and providing for their participation in the nomination and election of officers. Other means of integrating the activities of the National Society and regional and local sections should be developed but are not provided for in the proposed amendments.

The nomination and election of officers has been at the banquet held during the annual meeting. Only those members attending the banquet are able to participate in the election. Furthermore, since only one candidate is usually presented for each office the recommendation of the Nominating Committee is tantamount to election. A more democratic procedure is provided in the third amendment.

A large proportion of the Society's business including matters of policy is handled by the Executive Committee. It is composed of the President, the Vice President, the Secretary-Treasurer, the Editor, and the chairman of the two organic sections of the Society and the two immediate Past Presidents. The Committee believes the Society needs a larger and more representative body to assist in the development of Society policy and the guidance of the Society business. This is provided for by the formation of a Council, a body of elected representatives from all Divisions and regional, state, or local sections or branches.

The American Society of Agronomy should be the strong national professional society for all those trained in various phases of crop and soil science and their application. The needs and welfare of members can best be served by a strong society with permanent headquarters and a full time staff as suggested by the Committee on Policy and Program. At the same time the Society must provide an opportunity for professional groups within the Society to organize, develop programs, publications, and other activities to meet their needs. Our Society has not afforded members this opportunity so we have seen other organizations develop or expand in the field of agronomy. This we believe is contrary to the best interests of men engaged in soil and crop science and its application. We propose, therefore, that the Constitution be amended to provide for the formation of professional groups to be known as Divisions of the Society when their formation is in the interest of members and of the Society.

The four proposed amendments follow:

Amendment No. 1 Council

The Council shall consist of members of the Executive Committee, two elected representatives from each Division, two elected representatives from each Regional Branch, and six members elected at large. The representatives from Divisions and from Regional Branches shall serve for two years, Councilors at Large for three years. The President and Secretary of the Society shall be President and Secretary, respectively, of the Council.

A regular meeting of the Council shall be held in connection with the annual meeting of the Society. Special meetings may be called by the President.

The Council shall act as an advisory and policy making body in matters pertaining to the general functioning of the Society, shall be represented on all standing committees of the Society, and shall perform any other duties which may be prescribed by the Constitution or the By-Laws.

Amendment No. 2 Executive Committee

The Executive Committee of the Society shall consist of the President, Vice President, the two most recent Past Presidents, the Secretary-Treasurer, the Editor, the chairman of each Division, and councilors elected by the Council, one from each of the geographical regions of the Society.

Amendment No. 3 Nomination of Officers and Election of Officers

The Nominating Committee shall request each Regional Branch to propose one member of the Society for Vice-President and two members for Councilor at Large. Proposals should be made without reference to residence but solely on qualifications for office. Nominees for Vice-President shall not be named from the same Division in sucessive years. The Nominating Committee shall make two nominations for each position.

Election of the Vice-President and Councilors at Large shall be by mail ballot to all members.

Amendment No. 4 Divisions

The organic groups in the Society shall be called Divisions.

Divisions shall appoint their own officers and committees and make rules for their government. They shall hold at least a one-day program at the annual meeting of the Society.

A new Division may be formed by members of the Society when recommended by the Council and Executive Committee and approved by two thirds of those voting in a mail ballot. A division may be terminated by action of the Council and Executive Committee with approval of two thirds of the members of the Society voting in a mail ballot.

Your Committee further recommends that if these amendments are adopted by the Society a Committee of the Council or Society be appointed to revise the Constitution and By-Laws. That committee should consider many aspects of the Society's affairs including those resulting from the recommendations of the Committee on Policy and Program. It might modify some of the provisions of the four proposed amendments as those provisions are doubtless subject to improvement. Your Committee, however, believes the prompt adoption of the proposed amendments will do a great deal to enlist the

interest and active support of members in the Society's affairs and that is necessary for its best development.

We recommend the discharge of this Committee.

G. G. Pohlman
R. D. Lewis
F. W. Parker, *Chairman*

Submitted to Executive Committee on September 20, 1946.

STANDING COMMITTEES FOR 1947

FERTILIZERS

R. W. Cummings, *General Chairman*

SUBCOMMITTEE ON FERTILIZER APPLICATION

R. E. Yoder, *Chairman*
Leroy Donald
S. J. Gray
R. E. Blaser
C. J. Chapman
E. R. Collins
W. E. Colwell
J. W. Fitts
R. Q. Parks
F. R. Purvis
A. C. Richer
C. B. Sayre
H. J. Harper
S. B. Haskell
Arthur Hawkins
O. J. Kelley
George Lang
R. H. Lush
R. E. Neidig
A. J. Ohlrogge
M. B. Sturgis
V. A. Tiedjens
J. R. Taylor
A. Ulrich
S. C. Vandecaveye

SUBCOMMITTEE ON DIAGNOSIS OF PLANT NUTRIENT STATUS

R. L. Carolus, *Chairman*
R. H. Bray
H. D. Chapman
J. B. Hester
G. N. Hofer
B. A. Krantz
J. F. Reed
Michael Peech
G. D. Scarseth
G. W. Volk
Ed Walrath

SUBCOMMITTEE ON MODEL FERTILIZER LAW

F. E. Bear, *Chairman*
C. E. Millar
K. D. Jacobs
J. F. Reed

SUBCOMMITTEE ON FERTILIZER RATIOS

C. E. Millar, *Chairman*
R. V. Allison
R. P. Bartholomew
F. G. Baurer
C. J. Chapman
O. T. Coleman
E. R. Collins
M. H. Lockwood
H. B. Mann
A. L. Mehring
C. F. Simmons
J. R. Taylor
J. P. Thorne
S. C. Vandecaveye
R. E. Yoder
W. B. Andrews

SOIL TILTH

B. T. Shaw, *General Chairman*

FOR AMERICAN SOCIETY OF AGRONOMY

B. T. Shaw, *Chairman*
E. N. Fergus
T. M. McCalla
M. B. Russell
J. F. Lutz

Joint Committee with American Society of Agricultural Engineers

EXTENSION PARTICIPATION

H. B. Cheney, *Chairman*
Clyde Linsley
R. H. Tucker
J. C. Lowery
P. M. Burson
O. T. Coleman
C. S. Garrison
C. P. Wayne
O. S. Fisher

STUDENT SECTIONS

G. H. Dungan, *Chairman*
W. O. Collins
R. L. Cushing
R. J. Muckenhirn
R. C. Potts
Eric Winters
G. C. Klingman

PASTURE IMPROVEMENT

H. L. Ahlgren, *Chairman*
R. E. Blaser
B. A. Brown
E. M. Brown
M. Heath
M. A. Hein
R. L. Lovvorn
R. H. Lush
G. O. Mott
V. G. Sprague
T. M. Stevenson

MONOGRAPHS

A. G. Norman, *General Chairman*

For Crops:
H. H. Laude, *Chairman*
E. A. Hollowell
N. P. Neal

For Soils:
L. A. Richards, *Chairman*
Richard Bradfield
Hans Jenny

HISTORIAN

F. D. Keim

RESOLUTIONS

H. E. Meyers, *Chairman*
H. M. Tysdal
K. E. Beeson
F. B. Smith
J. D. Luckett, *ex-officio*

NEWS ITEMS

UNDER auspices of the War Department, a party of seven, including representatives of the U. S. Dept. of Agriculture and the State Department, is making a 30-day trip through Japan, Korea, and Formosa to study the food situation. Mr. K. D. Jacob of the Soils, Fertilizers, and Irrigation Division of the Bureau of Plant Industry, Soils, and Agricultural Engineering, is a member of this party and will make a study of the fertilizer production facilities as related to the increased production of foods.

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REPRESENTATIVES of the U. S. Dept. of Agriculture, The American Society of Agronomy, and the Association of American Fertilizer Control Officials met at the U. S. Plant Industry Station at Beltsville, Md., January 8 to 9, 1947, to discuss fertilizer problems. Special attention was given to factors that affect the production, distribution, and economics of fertilizer and the value that the

farmer receives for his fertilizer dollar. Those present enjoyed a varied program of prepared papers and informal discussion. D. S. Coltrane, President of the Association of American Fertilizer Control Officials, presided at the first day's session and F. W. Parker, Assistant Chief of the Bureau of Plant Industry, Soils, and Agricultural Engineering, presided the second day.

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PROFESSOR ANDREW BOSS, retired, of the University of Minnesota School of Agriculture, and long a member of the American Society of Agronomy, died at his home in St. Paul on January 13 at the age of 79. At the time of his death he was chairman of the Federal Farm Credit Board for the Seventh District, comprising Michigan, Wisconsin, and North Dakota. He is credited, among other things, with helping establish the College of Agriculture at the University of Minnesota and the farm research program of the U. S. Dept. of Agriculture.

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PROFESSOR A. F. BRACKEN of the Utah State College has been granted leave of absence to aid the Syrian Republic establish experimental and demonstrational projects in dry farming, cropping under irrigation, and range management. He is also starting work with sugar beets. A beet sugar factory is being built to begin operations in 1948. Professor Bracken's headquarters are with the Ministry of National Economy in Damascus.

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DOCTOR JAMES A. NAFTEL has been named Agronomist for the Southern Division of the Pacific Coast Borax Company, with headquarters in Auburn, Ala. Doctor Naftel served as a Major in the Field Artillery and saw combat service in the Italian campaign. Prior to entering the Army he was Associate Professor of Soils at the Alabama Polytechnic Institute.

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RESEARCH on the fundamental principles of phosphate fixation and release by soils, utilizing radioactive phosphorus, is being supported by a research grant from the Phosphate Research Committee of the fertilizer industry to the North Carolina Agricultural Experiment Station at Raleigh, N. C. The administrative committee of the industry has as members, J. E. Totman of Northeastern Chemical Industries, Inc., and F. W. Darner of the Tennessee Corp., with Dr. V. Sauchelli of the Davison Chemical Corporation as Chairman. The technical committee responsible for the work consists of Dr. H. B. Siems of Swift and Company, R. R. Hull of I. P. Thomas and Sons Co., H. E. Hendricks of the Knoxville Fertilizer Co., F. E. Boyd of the Virginia Carolina Chemical Corp., and Dr. V. Sauchelli as Chairman. The North Carolina Station has arranged for cooperation with the Cornell University Agricultural Experiment Station at Ithaca, N. Y., and the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md.

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Morphologic and Agronomic Variation in *Poa pratensis* L. in Relation to Chromosome Numbers[1]

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THE breeding of grasses in Minnesota was initiated in 1936 and studies on bromegrass, meadow fescue, orchard grass, and crested wheatgrass have been published (13, 16, 21, 26).[3] Also, preliminary results from a selection experiment with Kentucky bluegrass have been presented (12).

The present study, comprising a small part of the Kentucky bluegrass program, had three objectives, *viz.*, (a) to determine the extent of heritable differences in a number of characters of probable importance in a breeding program, (b) to determine the interrelationships of these characters, and (c) to determine the relationship between variation in chromosome numbers and the characters studied. A knowledge of the range of variability in these characters and their interrelationships is fundamental to a sound approach to the breeding of this species.

REVIEW OF LITERATURE

In Kentucky bluegrass, as in many grasses, the basic (x) number of chromosomes is considered to be seven (6, 9). This species, however, has been shown to have a remarkable range of chromosome numbers. Numbers have been reported by Åkerberg (2,3,4), Anderson (5), Armstrong (6), Brittingham (7,8), Brown (9), Müntzing (14, 15), Tinney (24), and others. The lowest number, $2n = 28$, and the highest, $2n = 124\pm$ were cited by Åkerberg (4). Numbers between 49 and 91 are fairly common and represent a complete aneuploid series.

The reproductive basis for this range of chromosome numbers has been established. Müntzing (14) first suggested apomixis. Later studies (2,3,7,10,20,24) have definitely shown that pollination is necessary for seed development. Hakansson (11) found in *Poa alpina* that fertilization of the two polar nuclei is neces-

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 2317, Scientific Journal Series, Minnesota Agricultural Experiment Station. Part of a thesis submitted to the faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of doctor of Philosophy. Received for publication October 4, 1946.

[2]Formerly Instructor, University of Minnesota, now Associate in Agronomy, Purdue University, Lafayette, Ind. The writer wishes to express appreciation to Dr. C. R. Burnham for guidance in all phases of the investigation and to Dr. H. K. Hayes for suggesting the problem and providing material and facilities for completing the work.

[3]Figures in parenthesis refer to "Literature Cited", p. 190.

sary for endosperm development. The endosperm had the 5n chromosome number, indicating that two unreduced endosperm nuclei had fused with a reduced nucleus from the pollen. Tinney (24) has described the mechanism of somatic apospory, the type of apomixis found in this species. Most workers (3,15,17,22,25) have agreed that apomixis in Kentucky bluegrass is not complete, and Brittingham (8) has summarized the types of sexual reproduction which may occur and which may lead to variation in chromosome numbers. The data of Myers (17) and Smith and Nielsen (22) suggest the segregation of genetic factors governing the degree of apomixis.

Morphological variability has been mentioned repeatedly. Brittingham (8) summarized some of the extreme differences which may be found. Myers, Garber, and Sprague (18,19,23) found differences in yields of clones under clipping when grown in association with white clover. Ahlgren, Smith, and Nielsen (1) found little or no relationship between yields of spaced plants and their clonal progeny in mowing plots or between yielding ability and disease reaction. They found that differences between clones were less pronounced in older sod. Hayes and Thomas (12) found little or no relationship between 2-year average yields in mowing plots and yields of seed progenies in mowing plots the first year after the seed was sown. Brown (9) stated that wide panicles, large spikelets, increased number of florets per spikelet, and long and numerous rhizomes tend to be associated with wide leaves, and that wide-leaved plants are generally low polyploids. In his material he observed a decline in vigor when chromosome numbers exceeded the hexaploid condition. Müntzing (15) found little difference in yield between diploid-triploid twins in the third year. Triploid plants had broader, thicker leaves, thicker culms, heavier seeds, and shorter spikelets. Pollen size was positively associated with chromosome numbers.

MATERIAL AND METHODS

Clonal lines of Kentucky bluegrass made available by the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, were derived from two sources. One source consisted of sod pieces collected in 1937 from many locations throughout Minnesota from which individual plants were isolated, grown in individual plant nurseries at University Farm and at the Southeast Experiment Station at Waseca, and allowed to increase clonally. The other source consisted of four seed lots from Ottawa, Canada, of strains Ottawa No. 3, Danish No. 939, Aberystwyth 993, and Svalöf 177. Individual plants grown from these seed lots were clonally increased at Waseca.

In September, 1939, the more vigorous clones, representing a diversity of plant types, were selected in these nurseries and two types of plantings were established from the selected clones. One planting consisted of small mowing plots, 49×77 inches in size, established with small plant pieces spaced 7×7 inches within the plot. Randomized complete blocks, replicated twice, each containing 22 clones and a check, Minnesota pasture No. 103, were used. Of the 13 blocks so established, 3 were used in this study. Two of these contained indigenous clones representing 35 locations in 12 counties. The third contained selections consisting of four clones from Ottawa No. 3, five each from Danish 939 and Aberystwyth 993 and eight from Svalöf 177. The second planting consisting of an individual plant nursery with duplicate plants (grown side by side) of each of the clones tested in the mowing plots.

In 1940, in the mowing plots, the number of plants in each plot surviving the winter of 1939 was recorded on May 7. At that time, the average diameter of plants in each plot was recorded and the vacant spaces filled, using plant pieces from the larger plants in the plot. Every 2 weeks through the summer, the average diameter of the plants in each plot was recorded to the nearest inch. Plots were mowed only as needed to prevent heading. Several times during midsummer, notes on drying (1 = green to 5 = dry) were taken. The July 27 notes showed the greatest differences and are reported here.

In 1941 and 1942, forage yields were obtained with a lawn mower by clipping a 16-inch swath through the long axis of each plot at a height of about 1½ inches. This was done generally when the grass reached about a 4-inch height. Clippings from each plot were collected, oven-dried, and are presented as grams of oven-dry forage per plot. Nine cuttings were made in 1941 and seven in 1942 and divided

into five monthly periods from April to September. No yields were taken in August of either year because of little growth. At each clipping an approximately equal portion of the dry forage from each plot was reserved for protein analyses. These were run each year on material bulked from all cuttings.

In the individual plant nursery, data were taken in 1941 and 1942 on plant height at flowering, green weight when the first seeds were beginning to ripen, basal diameter after forage was harvested, and leaf length and width. For leaf measurements, the second flag leaf below the inflorescence was taken from three randomly selected culms and measured from the ligule to the tip and at approximately the widest part of the leaf. Measurements of the three leaves were averaged to give a value for each plant. In addition, in both years, plants were classified in grades of 1 to 5 for mildew reaction (1 = resistant to 5 = susceptible), leafiness (1 = most to 5 = least leafy), and degree of culmage (1 = greatest to 5 = least density of flowering culms). Drying notes (1 = green to 5 = dry) were taken only in 1941 and are presented for the August 8 classification.

For studies on chromosome numbers, clonal pieces were transferred to 2-inch pots in the greenhouse. Root tips were killed and fixed in Müntzing's (14) modification of Navashin's killer for approximately 20 hours, washed, and stored in 70% ethyl alcohol. After dehydration with xylol, tips were embedded in paraffin and sectioned at 12.5 microns. Sections were stained by the crystal violet potassium iodide method and mounted in balsam or clarite.

In counting chromosomes, a 113× objective with N.A. 1.30 was used with 10× or 20× oculars. Drawings were made with or without the aid of a camera lucida and counts made from the drawings. Where later counts of the same figure or new counts from later slides of the same clone were obtained, no reference was made to the earlier count. This was done in order to obtain an unbiased estimate of the magnitude of error in making counts.

EXPERIMENTAL RESULTS

CHROMOSOME NUMBERS

Frequency distributions of chromosome numbers are presented in Table 1.

TABLE 1.—*Frequency distributions of chromosome numbers from mitotic root tip figures of clones from indigenous collections and from four introduced strains of Kentucky bluegrass, St. Paul, Minn.*

Source of material	Chromosome class										No. of clones
	49 to 52	53 to 56	57 to 60	61 to 64	65 to 68	69 to 72	73 to 76	77 to 80	81 to 84	85 to 88	
Indigenous......	9	7	8	6	5	–	–	–	–	–	35
Ottawa No. 3....	4	–	–	–	–	–	–	–	–	–	4
Danish 939......	–	–	1	3	1	–	–	–	–	–	5
Svalöf 177......	–	1	–	–	5	2	–	–	–	–	8
Aberystwyth 993	–	–	–	–	–	1	–	1	2	1	5

Counts were obtained on 35 of the 44 clones from the indigenous collections and numbers varied from 50 to 68. The clones from the four introduced strains fell into three distinct chromosome groups. Those from the Danish strain 939 and Svalöf 177 had a similar range of numbers. It was observed that different clones varied greatly in the ease with which suitable figures could be obtained.

The accuracy of chromosome counts was determined by selecting 11 figures at random and recounting after an interval of several months. In addition, new slides were made from 12 randomly selected

clones. An analysis of variance into "within and between" clones gave values for the standard error of a single determination of 1.5 and 1.7 chromosomes, respectively, for the two methods of checking counts.

SPREADING RATE

The periphery of spreading plants is not very clearly defined. Nevertheless, the analysis of variance indicated highly significant differences between clones in plant diameters at all dates after May 18.

The frequency distributions of average diameters for the 44 indigenous clones and 22 clones from introduced strains for three dates in 1940 are given in Table 2.

TABLE 2.—*Frequency distributions of mean plant diameters in mowing plots at three dates during the summer of 1940, University Farm, St. Paul, Minn.*

Date	Material	Diameter in inches													N	L.S.D.*	Mean
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0			
May 18	Indigenous	9	14	19	1	1	–	–	–	–	–	–	–	–	44	0.73	1.67±.07
	Introduced	2	6	13	1	–	–	–	–	–	–	–	–	–	22	—†	1.80±.08
July 13	Indigenous	–	3	6	14	16	1	3	0	0	0	1	–	–	44	0.68	2.75±.12
	Introduced	–	—	1	1	3	3	3	3	7	1	–	–	–	22	0.92	4.09 – .21
Sept. 7	Indigenous	–	1	0	3	6	9	9	9	3	1	2	0	1	44	1.06	3.96±.16
	Introduced	–	—	—	—	1	2	5	1	1	0	2	4	6	22	1.30	5.43±.31

*Least significant difference at the 5% point for comparing clones within each group of material
†No significant difference by F test.

Differences in plant diameters were found amoung the indigenous clones as early as May 18. These differences were associated with differential survival in the winter of 1939 (r = +.74). The rate of spreading through the rest of the season, however, was not influenced by this association since there was no significant correlation (r = +.25) between plant diameters on May 18 and the increase in plant diameters by the end of the season. That differences in spreading rate existed is shown in Table 2 by the fact that the range in plant diameters is much greater at the end of the season than at the beginning. The clones from the introduced strains had, on the average, a faster rate of spreading than those from indigenous collections, although plants outstanding in this respect were found in both groups of material.

YIELD

Frequency distributions of yields by months are presented in Table 3. The percentage of the total produced in each month as an average of two years was 18% in April, 32% in May, 26% in June, 9% in July,

and 15% in September. The inter-annual correlation coefficients for the five months were +.39, +.49, +.71, +.84, and +.49, respectively, and all were highly significant. When the average yields of clones in any one month were compared with yields in any other month, highly significant correlation coefficients ranging from +.40 to +.85 were obtained, indicating that high-yielding clones tend to give consistently higher yields month by month. However, when similar coefficients were calculated on the percentage of total yield produced in each month, no consistent relationships were found, indicating that clones giving similar total yields for the year may differ in the percentage of that total produced in the different months. From the standpoint of increasing the length of the summer grazing season it would be desirable to select strains producing a higher percentage of their total yield in July. However, no clone produced more than about 16% of its total yield in this month.

TABLE 3.—*Frequency distribution of average yields of clones in mowing plots by months, average of 1941 and 1942, University Farm, St. Paul, Minn.*

Month	Material	Grams dry forage per plot										N	Mean	L.S.D.*
		5	15	25	35	45	55	65	75	85	95			
April	Indigenous	—	—	3	12	6	12	10	1	—	—	44	48.9±1.90	23.5
	Introduced	2	4	8	2	1	4	1	—	—	—	22	30.5±3.71	17.6
May	Indigenous	—	—	—	—	1	6	10	9	9	9	44	75.5±2.16	25.3
	Introduced	—	—	—	—	4	8	3	4	3	—	22	62.3±2.88	32.0
June	Indigenous	—	—	—	2	9	12	9	10	2	—	44	60.0±1.96	21.0
	Introduced	—	—	2	3	6	2	6	3	—	—	22	52.3±3.37	28.2
July	Indigenous	3	17	11	12	1	—	—	—	—	—	44	23.0±1.51	13.1
	Introduced	7	10	3	2	—	—	—	—	—	—	22	15.0±1.97	11.3
Sept.	Indigenous	—	6	5	11	19	3	—	—	—	—	44	36.8±1.76	20.8
	Introduced	—	7	7	3	3	2	—	—	—	—	22	28.6±2.83	26.9

*Least significant difference at the 5% point for comparing clones within each group of material.

The yields of the clones from the indigenous material were, on the average, higher than those from the four introduced strains in every month.

PROTEIN CONTENT

As an average of two years, F values to test the significance of differences in protein content between clones, were slightly above the 5% point for the indigenous clones and slightly below the 5% point for those from introduced strains. The total range in percentages was 18.3 to 21.7 for the indigenous and 19.1 to 23.2 for the introduced material, with levels of significance at the 5 % point being 2.0 and 2.3, respectively. In both groups of material protein content differed significantly from one year to the next and the interactions of clones times years were highly significant.

STUDIES ON INDIVIDUAL PLANTS

Since duplicate plants, without replication, were studied in the nursery, no test of significance was available for comparing clones. However, a measure of the relative variability of the different characters was obtained by preparing frequency distributions in classes of the sampling error of a difference, using the mean of all clones as the center of class 0. These are shown in Table 4. The variance of these distributions, together with their standard errors calculated according to the formula $\sqrt{\frac{2V^2}{N-1}}$, are given in the last column of Table 4.

TABLE 4.—*Frequency distributions of deviations from the mean in classes from −6 to +4 times the sampling error of a difference for five characters studied in the nursery in 1941 and 1942, University Farm, St. Paul, Minn.*

Character	Material	Class											N	Mean	S. E. diff.	Variance
		−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4				
Plant height, in.	Indigenous	1	0	0	2	8	9	3	8	5	4	2	42	23.2	1.16	4.66±1.05
	Introduced	—	—	1	2	0	4	1	8	4	—	—	20	19.8	1.30	3.25±1.06
Basal diameter, in.	Indigenous	—	—	—	1	0	12	20	6	3	—	—	42	18.4	2.21	0.95±0.21
	Introduced	—	—	—	—	—	5	9	5	—	—	—	19	18.2	2.34	0.56±0.18
Green weight, grams	Indigenous	—	—	—	—	1	8	18	7	2	—	—	38	457	107	0.73±0.17
	Introduced	—	—	—	—	—	5	9	3	—	—	—	17	471	131	0.49±0.17
Leaf length, cm.	Indigenous	—	—	—	1	2	11	16	7	5	—	—	42	8.9	1.11	1.34±0.30
	Introduced	—	—	—	—	—	5	10	5	—	—	—	20	9.4	1.95	0.53±0.17
Leaf width, mm	Indigenous	—	—	—	—	—	9	23	10	—	—	—	42	3.7	0.66	0.46±0.10
	Introduced	—	—	—	—	2	5	8	2	2	1	—	20	4.2	0.58	1.60±0.52

It is apparent that in terms of the variation between duplicate plants, clones differed more in plant height than in the other characters studied. With the exception of leaf width, a somewhat greater range of variation was shown for the indigenous clones.

CHARACTER CLASSIFIED IN GRADES OF 1 TO 5

As shown in Table 5, indigenous clones showed somewhat more midsummer drying than those from introduced strains in the mowing plots in 1940, but there was no difference in the nursery in 1941. There was no relationship between drying notes taken on individual clones

in the two years (r=-.17). The indigenous clones were, on the average, somewhat less leafy and somewhat more stemmy than those from introduced strains, and a similar comparison for the individual clones from the indigenous collections gave a significant correlation coefficient of -.52. The majority of clones in both groups were resistant to mildew. Most of the susceptible clones, however, were in the indigenous material.

TABLE 5.—*Frequency distributions for various characters of clones classified in grades 1 to 5 in the nursery in 1941 and 1942, University Farm, St. Paul, Minn.*

Character	Material	Class									N	Mean
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0		
						Mowing Plots						
Midsummer drying*	Indigenous	—	—	—	—	17	7	15	3	2	44	3.61±0.09
	Introduced	2	2	3	1	4	5	3	2	—	22	2.91±0.23
						Nursery						
Midsummer drying†	Indigenous	1	2	9	13	4	7	0	2	—	38	2.63±0.12
	Introduced	—	2	2	4	4	4	0	2	—	18	2.89±0.20
Leafiness	Indigenous	—	6	12	17	5	2	—	—	—	42	2.32±0.08
	Introduced	12	2	2	3	—	—	—	—	—	19	1.47±0.08
Culmage	Indigenous	1	11	27	3	—	—	—	—	—	42	1.88±0.05
	Introduced	—	2	2	3	8	2	2	—	—	19	2.82±0.16
Mildew reaction	Indigenous	19	12	2	3	4	0	2	—	—	42	1.63±0.13
	Introduced	18	1	—	—	—	—	—	—	—	19	1.03±0.03

*1940 only.
†1941 only.

RELATIONSHIPS BETWEEN CHARACTERS

All possible associations between the 13 characters studied were tested by means of the simple correlation coefficients in Table 6. Only clones from the indigenous collections were used and the coefficients are based on 35 to 44 comparisons. In the next to the last column are given the coefficients for determining associations between chromosome numbers and the characters studied. The number of pairs for these latter comparisons are in the last column.

Of 91 associations tested, 24 exceed the 5% or 1% levels of significance. Seven of the significant associations involved green weight in the nursery while only one involved yield in mowing plots. However, with the exception of green weight vs. plant diameters (r=+.84) in the nursery, the coefficients are generally too low to be of value for prediction purposes. There is a consistent lack of relationship between characters of individual plants and similar characters in mowing plots and between characters that denote or are associated with vigor as individual plants and yield of clipped forage, indicating that little information concerning behavior under mowing treatments can be obtained by observing individual plants.

TABLE 6.—*Coefficients of correlation between characters of indigenous clones studied in mowing plots and in the nursery based on 1941 and 1942 averages, except as indicated, University Farm, St. Paul, Minn.*

Character	Mowing plots: Dormancy, 1940	Mowing plots: Yield	Mowing plots: Protein, %	Nursery: Plant Height	Nursery: Basal diameter	Nursery: Green weight	Nursery: Leaf length	Nursery: Leaf width	Nursery: Mildew reaction	Nursery: Leafiness	Nursery: Degree of culmage	Nursery: Dormancy, 1941	Chromosome number: r	Chromosome number: n
Mowing plots:														
Spreading rate, 1940	−.34*	−.10	−.12	−.11	+.02	+.48**	−.08	−.01	+.17	−.44**	+.03	−.02	+.41*	35
Summer dormancy, 1940		−.18	−.24	+.45**	−12	−.10	−.31*	+.19	+.41**	+.24	−.29	−.17	+.16	35
Yield			+.38*	+.16	+.16	−.02	−.08	−.24	−.04	+.22	+.14	+.02	−.22	35
Protein, %				+.04	+.44**	+.36*	+.21	−.10	−.16	−.42**	+.46**	−.17	−.31	35
Nursery:														
Plant height					+.27	+.35*	−.25	+.28	+.27	+.23	−.13	−.23	+.33	34
Basal diameter						+.84**	−.18	−.04	+.19	−.17	.00	−.46**	−.07	34
Green weight							+.13	+.35*	+.34*	−.31	+.07	−.36*	+.11	29
Leaf length								+.50**	−.18	−.53**	+.50**	+.01	−.24	34
Leaf width									+.12	−.36*	+.21	−.01	+.19	34
Mildew reaction										+.21	−.16	−.01	+.48**	34
Leafiness											−.52**	+.11	+.22	34
Degree of culmage												−.03	−.10	34
Summer dormancy, 1941													+.21	31

*Significant at the 5% level.
**Significant at the 1% level.

With the exception of a significant positive relationship between chromosome numbers and mildew susceptibility ($r=.48$) and between chromosome numbers and spreading rate ($r=.41$), there is little or no relationship between chromosome numbers and the characters studied. Apparently, chromosome numbers may vary over a rather wide range without having a marked effect on yield or other morphologic or agronomic characters.

DISCUSSION

The method of reproduction in Kentucky bluegrass may provide a logical explanation for the lack of relationship found in this study of chromosome numbers to other characters. The chromosome number of a particular biotype is maintained by apomixis. However, because of the facultative character of apomixis, further variation in chromosome numbers is brought about by occasional normal sexuality and by fertilization of unreduced eggs with gametes varying in chromosome number. Furthermore, the particular chromosomes which may be lost or duplicated in these sexual or partially sexual processes depend upon chance distribution at anaphase. Hence, the relative numbers of particular chromosomes, together with the genes they carry, may be widely different for different plants even though total chromosome numbers may be similar. This behavior, coupled with the probable heterozygosity of the species as a whole, tends to vitiate the associations of chromosome numbers with morphological characters which might otherwise be found and which are often associated with a tetraploid in relation to its immediate diploid progenitor.

The lack of relationship between characters of individual plants and yields in mowing plots are in general agreement with the results of Ahlgren, Smith, and Nielsen (1). In the nursery, yield of individual plants depends partly upon the height and basal diameter of the plant. In yields taken on short growth from solid stands, these two characters have no relation to yield. In tests of significance of differences of yields in mowing plots it was observed that there was a tendency toward lower F values the second year, indicating a leveling off effect in the older sod, a tendency which is probably not so evident under higher nitrogen levels (1) or when bluegrass is grown in association with white clover (19). These results therefore suggest the necessity of using adequate fertilizer practices in connection with a selection program based on clipping treatments and to get maximum benefits from superior strains.

SUMMARY

Forty-four clones of Kentucky bluegrass from a Minnesota collection and 22 clones from four strains introduced from Ottawa, Canada, were studied in small clonally propagated mowing plots and as individual plants in a space-planted nursery.

Chromosome numbers of 35 indigenous clones varied from 50 to 68 and for the 22 clones from introduced strains from 50 to 85.

In the mowing plots, the clones from introduced strains had, on the average, a greater spreading rate and showed less summer dormancy in 1940 than the indigenous clones, although outstanding clones were found in both groups of material. The indigenous clones, on the average, yielded more in the two years 1941 and 1942. High-yielding clones tended to give higher yields month by month, although there was some variation in monthly distributions of yields of similar yielding clones. Significant differences were found in protein content of different clones.

In the nursery, plant height showed a much greater range of variation than did basal diameter, green weight, leaf length, or leaf width. The range of variation was generally greater for the indigenous clones. In characters classified in grades of 1 to 5, the two groups were similar in summer dormancy, and most clones were resistant to mildew, although a few susceptible clones were found in the indigenous group. The indigenous clones were, on the average, less leafy and produced a greater density of culms than those from introduced strains.

Of 91 associations between 14 characters studied, 24 correlation coefficients exceeded the 5% level of significance but with few exceptions did not exceed the value r=.50. It was concluded that the behavior of spaced plants could not be used as a very reliable criterion for behavior in mowing plots. Chromosome numbers were positively associated with spreading rate and with mildew susceptibility. No other significant associations were found, indicating that chromosome numbers in Kentucky bluegrass may vary over a considerable range without having an appreciable affect on morphologic characters or agronomic behavior.

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A Selection Experiment With Kentucky Bluegrass[1]

H. L. Thomas and H. K. Hayes[2]

KENTUCKY bluegrass, *Poa pratensis*, L. according to Hitchcock, is the most important species of Poa. It is used widely as a lawn grass in the cooler regions and is the standard permanent pasture grass in the humid regions. It is widely distributed as a pasture grass in Minnesota and for that reason it seemed of interest to learn the value of selection as a means of isolating high-yielding pasture types as well as types that were adapted for lawn purposes.

A recent paper by Ahlgren, Smith, and Nielsen (1)[3] has reviewed other experiments on selection with *Poa pratensis*. The present report includes a summary of the performance of clonal lines and of selected seed progenies in mowing plots when cut at an approximate height of 4 inches. Observations were made also on desirability for lawn purposes with particular reference to appearance in summer.

MATERIAL AND METHODS

In 1937, divots of Kentucky bluegrass were collected from 60 old pastures and waste places throughout Minnesota, the material being taken from a wide range of soil and environmental conditions. These divots were broken down to individual plants and 281 vigorous plants with different growth habits were selected and increased as clones.

From 30 of these clones seed was saved under bag in 1939 for testing in comparison with open-pollinated seed of the same clones. Seedlings were started in the greenhouse in the spring of 1940 and transplanted into 4×4 foot rows in the field. Plots consisted of 10 plants and there were two randomized replications each containing paired adjacent plots of seed progenies from bagged and open seed from each clone.

In the fall of 1939 the 281 clones from Minnesota origin, 3 selected from a variety introduced from Svalöf, and 2 from Ottawa were selected for testing in randomized block trials. Each block consisted of 23 clones, one of which, called the check, was established by clonal reproduction from 11 plants increased from a single pasture. Care was taken to plant the checks so that clones of each of the 11 plants were used with equal frequencies in each check plot. The 286 clones were placed in 13 groups and the clones in each group were randomized within each of two blocks. Each plot was established by setting clonal pieces 7 inches apart each way in a rectangle containing 7×11 pieces. Satisfactory sods were formed during 1940 and these were clipped for forage yield in 1941 and 1942.

There was a relatively good agreement between the performance of the 281 clonal lines in 1941 and 1942 and selections were made of clonal lines on the basis of total average yield using the check variety as a means of classification of the performance of the clonal lines. Significant differences at the 5% point were established by analysis of variance for each group of 23 clonal lines. The individual clones were classified in relation to the check variety as follows: Class 1, those that yielded 3 times the S. E. of a difference at the 5% point above the check, yields in all cases being taken in dry matter. Other classes were made in the same

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[3]Figures in parenthesis refer to "Literature Cited", p. 197.

manner, class 4 representing those that did not differ significantly from the check, while classes 5 and 6 yielded less than the check.

Selections of the better clones were made also on the basis of desirable appearance, freedom from diseases, and yield during the summer months. Some clones were selected from all classes for yield and all clones selected were increased vegetatively for seed production. Seed from these selected clones was saved in 1943.

Forty-eight selected clones and six introductions from the Wisconsin experiment station were sown in the fall of 1943 in 8×8 foot broadcast plots with four randomized replications. Seed from unbagged plants was used. White clover was added to replicates 3 and 4 in the spring of 1944. During 1944 and 1945 these plots were clipped for forage yield each time the grass reached a height of approximately 4 inches.

The yields in mowing plots from seed progenies were analyzed in a manner similar to those of the clonal plots. A check variety from commercial seed obtained from Northrup King & Co. was included. In this study classes for yield were established in a similar manner as described for the clonal mowing plots.

Fertilizer was applied uniformly to the whole experimental area as it appeared to be needed to keep the material in a thrifty growing condition. This consisted of 200 pounds per acre of ammonium sulfate in the spring of 1944, 200 pounds per acre of a 10–8–6 mixture in July 1944, and 250 pounds per acre of a 6–2–1 mixture in October 1945. During part of the years notes were taken on vigor and desirability for lawn purposes during August and also on rapidity of spring recovery. Nine representative strains were studied for protein content of the last clipping in 1944.

EXPERIMENTAL RESULTS

There was no significant difference in forage yield between plants established from bagged vs. those established from unbagged seed. Notes on plant type did not indicate greater variability from open-pollinated than from bagged seed. This lends added evidence to the parthenogenetic development of seed as reported by Tinney (3).

With 45 strains from which forage yield was obtained in clonally reproduced plots in 1941 and in 1942, and from seed reproduction in 1944 and 1945, total yield and yield for the summer months was used as a basis for classification, with the class interval being the least significant difference at the 5% point, as described under methods. Table 1 shows the range of variability in classes. Average yields in

TABLE 1.—*Average yield class frequencies 1941–42 compared with yield classes in 1944 and 1945, season total and summer yield.*

1941–42 average	1944						1945					
	1	2	3	4	5	6	1	2	3	4	5	6
				Season Total								
2	–	–	6	9	2	–	–	–	6	11	–	–
3	–	–	4	11	1	–	–	–	8	8	–	–
4	–	1	1	4	–	–	–	–	1	2	2	1
5	–	–	4	1	–	–	–	–	1	2	2	–
6	–	–	–	1	–	–	–	–	–	–	1	–
				Summer								
1	–	1	1	–	–	–	–	–	–	2	–	–
2	–	1	6	2	1	–	–	–	1	9	–	–
3	2	1	4	11	3	–	–	–	5	14	2	–
4	–	2	2	2	2	–	–	–	1	3	3	1
5	–	–	2	1	–	–	–	–	–	1	2	–
6	–	–	1	–	–	–	–	–	–	–	1	–

1941–42 were compared with yields in 1944 and 1945 separately, the correlation coefficient being used as a measure of relationship (Table 2). A previous report (2) showed significant differences in productivity between strains in 1941 and 1942 in clonally reproduced plots but no relation between the yields in clonally reproduced plots and yields from seed progenies in 1944. Analysis of variance to be given later showed significant variability in yield at the 5% point from seed plots in 1944 and wide differences in yielding ability in 1945. The correlation coefficient for yielding ability between average yields in clonally reproduced plots in 1941–42 and from seed progenies in 1945 was +.62. Yields in 1944 from seed progenies showed no correlation to yield in 1945 or to average yield in clonal progenies in 1941–42.

TABLE 2.—*Interannual correlation coefficients for season total yields of 45 bluegrass strains.*

Population	Correlation coefficient
Yield 1941 with yield 1942	+.85**
Average yield 1941 and 1942 with yield 1945	+.62**
Yield 1944 with yield 1945	−.03
Average yield 1941 and 1942 with yield 1944	−.18

**Significant at 1% point.

Separate analyses of variance were computed for 1945 and 1946 total forage yield (dry weight) for the purpose of studying strain yields alone and in combination with white clover (Tables 3 and 4).

TABLE 3.—*Analysis of variance 1944 dry forage yields season total from bluegrass strain test.*

Source of variation	Degrees of freedom	Mean square	F
Blocks	1	886789	2.59
Clover	1	39931338	116.58**
Strains	55	521589	1.52*
Clover × strains	55	283696	——
Error	111	342526	——
Total	223		

*Significant at 5% point.
**Significant at 1% point.

TABLE 4.—*Analysis of variance 1945 dry foliage yields season total from bluegrass strain tests.*

Source of variation	Degrees of freedom	Mean square	F
Blocks	1	14241	2.91
Clover	1	1232552	251.90**
Strains	55	13568	2.77**
Clover × strains	55	4846	——
Error	111	4893	——
Total	223		

**Significant at 1% point.

There was a significant difference between strains and the addition of white clover gave a large increase in yield. But since there is no significant interaction between clover and strains, it appears that clover had no measurable effect on the relative yield of strains.

Because the 1945 data gave wide differences between strains, this was used in a study of behavior of yields in three seasons, *viz.*, spring (up to July 3), summer (July 3 to August 17), and fall (August 17 to October 6). The analysis of variance for this study is shown in Table 5.

TABLE 5.—*Analysis of variance for 1945 yield, using division of forage production into spring (up to July 3), summer (July 3 to August 17), and fall (August 17 to October 6).*

Source of variation	Degrees of freedom	Mean square	F
Plots	223	4189	7.05
Seasons	2	1593097	261.98**
Seasons × blocks	2	608	1.02
Seasons × strains	110	1420	2.39**
Seasons × clover	2	55460	93.36**
Seasons × strains × clover	110	516	——
Error	222	594	——
Total	671	——	——

**Significant at 1% point.

The interaction between seasons and strains is significant, showing that strains superior in the summer and fall are not always superior in the spring, as would be expected.

Table 6 shows actual total yield for the three seasons for plots with and without clover. It will be noted that plots with white clover were relatively more productive in summer and fall than in the spring.

TABLE 6.—*Effect of white clover mixture on seasonal production of dry forage in pounds from bluegrass strains season 1945.*

	Spring	Summer	Fall
No clover	19,628	6,860	2,480
Clover	25,034	15,991	4,560

An idea of the practical value of the strains for pasture is given in Table 7. This includes the average of two plots with clover and two without and represents seven cuttings in 1944 and six cuttings in 1945. Although soil at University Farm, St. Paul, is a silt loam with a gravel subsoil at 30 to 40 inches that is not particularly well adapted to bluegrass, yields during 1944 and 1945 were very good due to relatively adequate rainfall during the two years.

TABLE 7.—*Yield of forage in pounds per acre at 15% moisture.*

Year	Highest strain	Lowest strain	Commercial check
1944	4,904	3,046	3,437
1945	2,835	1,034	2,117

Nine representative strains and the commercial check were used for a study of protein content. From the last clipping (September 14, 1944) analyses were made from grass alone, the white clover being separated from the last two replicates. Crude protein averaged from 23.77% to 27.66% of the dry matter. There was a statistically significant difference between strains. The average of the plots without clover was 24.7% and with clover 26.00% and this difference was also significant.

Table 8 summarizes the data taken on rapidity of recovery in the spring and also vigor and desirability for lawn purposes during August. These were recorded by observation on a scale of 1 to 5, with 1 the most desirable.

TABLE 8.—*Summary of observational data on rapidity of recovery in spring and vigor and desirability for lawn in August for 55 bluegrass strains with commercial check, notes taken on a scale of 1 to 5, with 1 most desirable.*

	Range high to low strain average of four plots	Commercial check average	F value for strains	Interannual correlation coefficient
	Rapidity of Spring Recovery			
April 1945....	1.75–5.00	3.25	9.11**	+0.828**
April 1946....	2.50–4.80	3.80	12.64**	
	Vigor and Desirability for Lawn in August			
August 1944..	1.50–3.50	3.00	3.34**	+0.629**
August 1946..	1.50–4.50	3.25	4.88	

**Significant at 1% point.

In each case there were statistically significant differences between strains and there was a significant correlation between comparable data in the two years. The average of the commercial check was always intermediate in the range of the strain averages. In 1945 there was a correlation of +.76 (highly significant) between observational data taken in the spring and acutal yield during May and June.

SUMMARY

Collections of bluegrass were made from scattered areas in the state of Minnesota. These were broken down to single plants, increased clonally, and the strains studied intensively for agronomic value.

Yields of clonal lines of 55 strains in 1941 and 1942 and of seed progenies in 1945 gave highly significant correlation coefficients. Yields in 1944 gave no significant correlation values with other years. Addition of white Dutch clover to the bluegrass increased forage yield tremendously and the same strains were high yielding both with and without clover.

Clover appeared to have a greater proportionate effect on yield in summer and fall than in spring. There was a rather small but significant difference in protein content between strains. The grass from plots with clover was slightly but significantly higher in protein content than from plots of grass grown alone. Data on vigor taken by

observation in April and August gave significant variation for strains and significant inter-annual correlations.

Several strains were more productive of forage than the commercial check and 18 strains have been selected and planted in a new test for further study.

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Breeding Hard Red Winter Wheats for the Northern Great Plains Area[1]

E. R. Ausemus and R. H. Bamberg[2]

THE development of more hardy adapted varieties of hard red wheats has resulted in a northward expansion of the area devoted to the culture of winter wheats. Low temperatures, combined with other environmental factors to which these wheats often succumb, have limited their wider use. Winter wheat usually matures earlier than spring wheat thus often allowing it to escape hot dry winds and the rusts that frequently injure spring wheats. When winterkilling is not too serious a factor, winter wheat outyields spring wheat. It also has the advantage of giving a better distribution of labor. Winter wheat should, therefore, be grown instead of spring wheat in localities where this is possible.

The states included in the northern section of the hard red winter wheat area are Minnesota, South Dakota, Wyoming, and Montana. The first three of these states each grow between 100 and 200 thousand acres of winter wheat while Montana grows over a million acres annually. The development of more hardy varieties has made possible the successful growing of these wheats in areas where they were frequently injured by winterkilling. Some of these varieties are Minturki, Minhardi, Marmin, and Yogo.

Most of the relatively hardy winter wheat varieties which have been developed for the northern section have been as desirable in quality as the better spring wheats. Greater disease resistance, such as resistance to leaf and stem rusts and ordinary and dwarf smut, is also needed. There is a demand, therefore, for winter wheats with greater winter-hardiness, more disease resistance, and better milling and baking quality than those now available for growing in this area. This paper discusses the breeding work now being done for the improvement of winter wheat varieties adapted to the northern region.

WINTERHARDINESS

One of the major problems in the improvement of wheats for the northern region is the development of more winterhardy varieties. Winterkilling may be due to any or all of four causes, *viz.*, (a) heaving, (b) smothering, (c) physiologic drought, and (d) direct effect of low temperatures on the plant tissues. Winter wheats vary greatly in their

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ability to resist cold and to survive, and many reports have been published on the relative resistance of winter wheats to winterkilling.

In a well-balanced breeding program, it is essential that new wheats with either greater winterhardiness or those containing other genetic factors controlling winterhardiness be continually sought. Recently, some wheats received from China have been tested for winterhardiness under the severe winter conditions at the Minnesota experiment stations. Three of these varieties, known as Nanking 68 (F.P.I. 124279)[3], Nanking 221 (F.P.I. 124307), and Nanking 239 (F. P. I. 124311), have had winter survival percentages of 63, 55, and 34, respectively, while Minturki had 58% and Minhardi 49% survival during the years they were tested. Crosses have been made between these Chinese wheats and the present commercially grown varieties and new hybrid strains having greater disease resistance.

Because of the necessity of obtaining greater disease resistance and higher quality in the commercially grown winter wheats, a backcross program involving Minturki and Marmin as the recurring parents and either Hope or H-44 (two spring wheats resistant to leaf and stem rusts) as the non-recurring parents has been used. As many as four backcrosses have been made. The problem in this type of cross then becomes one of obtaining hybrid strains with as much winterhardiness as the recurring parents.

The plan has been to grow the early generation material, F_1 to F_5, by the pedigree method in the field, since the conditions are ideal at St. Paul in most years for measuring winterhardiness. Three to four replications of the F_3 to F_5 generations are grown. The seed is spaced so that individual plants can be harvested and selections are made from lines having the highest precentage of strong, healthy plants.

Milling and baking tests are first made on the grain from nursery rod row yield trials in F_6 and later generations. After three years of nursery trials, the strains having the best agronomic characters, disease resistance, yield, and quality are advanced to 1/40 acre field plots. Data obtained on the varieties and strains grown in nursery and plot tests at St. Paul and Waseca, Minn., during the years 1942 to 1945, are given in Table 1. The varieties were completely winterkilled in plots at St. Paul in 1943 and 1944 and in the nursery in 1943, and at Waseca in 1945.

The data show that a number of the hybrid strains having either Hope or H–44 as one of the parents were as winterhardy and yielded as well as or superior to the check varieties, Minturki, Marmin, and Minhardi.

Since cold resistance is so important in the northern area, varieties and hybrid progenies grown in the plots and nursery trials also were tested in controlled temperature chambers. The procedure used was to grow the young plants in the greenhouse in pots, five plants per pot for 4 weeks, harden them in one freezing chamber at a temperature of 1° to 2° C above zero for 10 days, wet them thoroughly, and put them in another freezing chamber at a temperature of minus 11° or

[3]Accession number of the Division of Plant Exploration and Introduction, Bureau of Plant Industry, soils, and Agricultural Engineering, U. S. Dept. of Agriculture.

TABLE 1.—*Summary of data on agronomic characters, rust infection, and milling and baking characters of winter wheat varieties grown in plot and nursery trials and three spring wheats grown in plots at St. Paul and Waseca, Minn., in 1942 to 1945.**

Variety	Minn. or N.S. No.	Winter injury, %	Agronomic data: Rust, Leaf, %	Agronomic data: Rust, Stem, %	Agronomic data: Yield, bu.	Agronomic data: Bushel weight, lbs.	Milling and baking characters†: Wheat protein, %	Flour yield, %	Loaf vol., cc	Carotinoid pigments, P.P.M.	Crumb, 0–10: Color	Crumb, 0–10: Grain	Crumb, 0–10: Texture
Winter Wheats													
Plot trials:													
Minturki	1507	42	39	40	19.1	58	12.0	76.6	748	4.60	7.0	6.6	7.4
Marmin	2614	39	45	25	20.5	58	12.2	74.2	684	4.25	7.4	6.9	7.1
Hope×Minturki[2]	2713	37	1	Trace	21.9	60	11.9	74.7	726	3.18	7.9	6.7	7.7
H-44×Minturki[2]	2714	43	1	Trace	21.1	57	12.1	72.3	792	3.87	7.8	6.7	7.7
Nursery trials:													
Minturki	1507	28	40	38	23.0	59	12.0	75.9	700	4.76	5.7	6.2	6.9
Minhardi	1505	17	54	68	20.6	57	11.4	75.4	674	4.60	6.3	6.1	6.8
H-44×Minturki[2]	II-31–43	23	10	5	24.9	59	12.2	76.6	722	4.02	7.7	6.0	7.2
H-44×Minturki[4]	II-35–50	21	12	Trace	26.7	60	12.0	76.7	683	3.16	7.7	6.2	7.4
H-44×Minturki[4]	–52	13	12	Trace	26.7	60	12.5	77.1	714	3.22	8.1	5.8	7.3
Hope×Minturki[4]	–19	28	5	Trace	21.4	60	12.2	76.0	688	2.99	7.7	5.4	7.3
Hope×Minturki[4]	–20	28	10	Trace	25.8	60	12.4	76.0	666	3.14	7.8	6.0	7.3
H-44×Minturki[3]	II-36–1	14	6	Trace	25.8	61	12.7	77.3	684	3.47	7.6	6.1	7.8
H-44×Minturki[3]	–3	15	2	Trace	25.3	60	12.4	77.6	708	3.53	7.8	5.9	7.5
H-44×Minturki[3]	–8	28	5	Trace	25.0	59	12.4	75.2	728	3.94	7.8	5.8	7.5
H-44×Minturki[3]	–14	26	13	Trace	21.2	59	13.0	75.2	759	4.25	7.7	5.9	7.9
Marmin×$\frac{\text{H-44}}{\text{Minhardi}}$	–26	34	5	11	20.7	58	12.3	75.7	662	3.78	7.4	5.8	7.2

Marmin × H-44/Minhardi	-29	37	5	5	24.8	60	12.5	75.7	728	2.93	8.1	5.5	7.5
Marmin × H-44/Minhardi	-30	35	8	8	22.7	60	12.8	74.0	735	3.16	7.9	5.8	7.8
Minard/Minhardi × H-44/Minhardi	-23	30	9	22	23.8	59	12.9	77.3	733	3.45	8.1	5.6	7.3
Minard/Minhardi × H-44/Minhardi	II-36-32	36	5	4	23.7	60	13.0	75.6	659	2.79	7.9	6.2	7.3
Minard/Minhardi × H-44/Minhardi	-34	27	5	4	24.9	61	13.4	76.1	730	2.83	8.2	5.8	7.8
Minard/Minhardi × H-44/Minhardi	-35	30	12	7	26.1	62	12.9	78.2	696	2.87	8.1	6.3	7.7
Minard/Minhardi × H-44/Minhardi	-42	16	7	10	28.6	60	12.3	78.7	630	3.69	7.0	5.3	6.8
Spring Wheats													
Plot trials:													
Thatcher	2303	—	73	Trace	23.1	56	13.1	75.0	734	3.15	7.5	6.3	7.9
Rival	2670	—	24	Trace	25.8	58	13.3	77.1	725	2.71	7.8	6.3	8.1
Newthatch	2752	—	28	Trace	27.3	55	13.8	76.5	765	3.06	7.7	6.2	7.8

*Crop failures due to winterkilling of field plots at St. Paul in 1943 and 1944, and in rod-row trials at St. Paul in 1943 and at Waseca in 1945.
†Milling and baking data obtained by Dept. of Biochemistry, University of Minnesota.

12° C for 24 hours. The plants were placed in the shade for 24 hours after removal from freezing chambers then placed in the greenhouse and the survival notes taken after 10 days. Correlation coefficients were calculated between the winter injury in the field and cold resistance as determined by the freezing in the cold chambers during the years 1935 to 1942, inclusive. These are given in Table 2.

TABLE 2.—*Correlations between winter injury of winter wheat varieties and strains in the field and in controlled freezing tests.*

Year	Number of pairs	Coefficient of correlation
1935	39	−0.08
1936	34	0.49**
1937	27	0.28
1938	96	0.25*
1939	138	0.07
1941	81	−0.21

*Exceeds the 5% point.
**Exceeds the 1% point.

The low correlation coefficients obtained in these studies between winter injury in the field and cold resistance as determined by controlled tests do not agree with results obtained by previous workers as reported by Salmon (3)[4], Hill and Salmon (1), Laude (2), Worzella and Cutler (5), and Weibel and Quisenberry (4). These small correlation coefficients probably were due to the fact that strains and varieties under test are all rather highly cold resistant or perhaps that the field test does not always bring out the true differences in cold resistance.

Breeding for winterhardiness is being done in Montana for two distinct conditions, dwarf smut areas and areas where dwarf smut is not yet a factor. Two dwarf smut-resistant varieties developed in Utah, Cache and Wasatch, are sufficiently winterhardy for the first area but not for most sections of the state.

In breeding for resistance to dwarf smut, selections have been made from Martin × Tenmarq[3] and from Turkey (C.I.11530) × Oro.[5] A number of these selections yield better than Cache and Wasatch and also appear more winterhardy.

Resistance to dwarf smut probably will be needed in the most winterhardy varieties within a few years. In order to obtain winterhardy varieties that are resistant to dwarf smut if it spreads to the more important winter wheat areas, Wasatch has been crossed and backcrossed to Yogo and two other very winterhardy wheats.

DISEASE RESISTANCE

The second important phase of the winter wheat improvement program at the Minnesota Experiment Station has been the breeding for stem and leaf rust resistance. Minturki and Marmin, the two commonly grown winter wheats in the eastern part of the Northern Great Plains area, are somewhat resistant to stem rust, but susceptible to

[4]Figures in parenthesis refer to "Literature Cited," p. 205.
[5]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

leaf rust. Hope and H-44 (two spring wheats) were used in crossing with the winter wheats because of their resistance to leaf and stem rust and to loose smut. The reaction to leaf and stem rust of the F_1 to F_5 generations is obtained in the material grown for winterhardiness studies. Artificial local epidemics of leaf and stem rust are created, using all prevalent races of both rusts. Selections for disease resistance are made then in the lines having both winterhardiness and disease resistance.

The data given in Table 1 on the field plots and rod-row trials show that a large number of the backcross lines have only a trace of stem rust as compared with 39% infection on Minturki and 68% on Minhardi. In leaf rust resistance, the hybrid lines averaged from a trace to 13% infection while Minturki had 40% and Minhardi 68% infection.

An H-44 × Minhardi selection, N. S. No. 11-26-29, resistant to both rusts, has been crossed with other winterhardy wheats lacking rust resistance. Hybrid lines, grown in rod-row trials, have shown a high degree of leaf and stem rust resistance.

Hope was found to be susceptible to stem rust in Peru, and its mature plant type of resistance is not an entirely satisfactory means of controlling stem rust. In controlled experimental tests, where environmental conditions have been favorable to infection with stem rust, considerable infection has been obtained on several highly resistant wheats.

Certain spring wheats, such as some of the Kenyas, K58 and 117A, McMurachy, Kenya-Gular, Timstein, and Red Egyptian, have been found to be resistant in the seedling stage to a large number of stem rust races prevalent in the United States.

With the finding of the newer sources of seedling resistance in the Kenyas, McMurachy, Kenya-Gular, Timstein, and Red Egyptian, it seems desirable now to combine this type of resistance with the adult or mature plant type of resistance carried by the present winter wheat varieties. Such crosses are now being made so that physiologic resistance to all races of stem rust may be transferred eventually to winter wheats.

The discovery of a biotype of stem rust race 15, called 15B, presents another problem. This biotype is differentiated by Rival (a spring wheat) being resistant in the seedling stage to race 15, and susceptible both in the seedling and mature plant stage to race 15B. Thatcher, some of the Kenyas, Timstein, Hope, and their winter and spring wheat derivatives are susceptible to race 15B both in the seedling and mature plant stages under certain controlled experimental conditions. Two Kenya wheats, K58 and 117A, are highly resistant to 15B and Red Egyptian is moderately resistant. Crosses are now being made between these wheats which are resistant to race 15B and some of the better Hope × Minturki and H-44 × Minturki backcross strains.

Another important problem in this area is leaf rust resistance. The present commercially grown winter wheats are susceptible to leaf rust, and the Hope or H-44 × Minturki backcross strains as well as most of the spring wheats having the Hope type of leaf rust resistance were

severely attacked by leaf rust in 1944 and 1945; the winter wheats much less than the spring wheats probably because they matured earlier. Recently, work has been done on the identification of the leaf rust races found in this area. According to the present information, it seems necessary to use several varieties to combine resistance to the various leaf rust races in a single variety as none was highly resistant during the last two years. There is, however, a difference in their reaction to individual races now prevalent. Three varieties of spring wheats, Timstein, Brevit, and Carina, each carrying resistance to certain leaf rust races, are now being crossed in an attempt to combine resistance to a number of races in a single variety. This resistance will then be transferred to the winter wheats. New sources of resistance are also being sought and will be used in the breeding program.

The present plan is to add particular types of resistance in the seedling stages to the seedling resistance and mature-plant resistance now carried by commercially important winter wheat varieties. The aim is to retain the resistances to rust now available and incorporate resistances to new races wherever possible. The backcross method will be used extensively. In this manner it appears possible to solve new problems soon after they become known.

In the western part of the Northern Great Plains area there are two lines of attack on the smut problem, breeding for resistance to dwarf smut and breeding for resistance to the races of ordinary smut. In the areas where dwarf smut is severe, it overshadows ordinary bunt because of its destructiveness and the complete lack of control methods other than the use of resistant varieties.

In breeding for resistance to dwarf smut the factors in Ridit, Hussar, and Martin make these varieties fairly effective parents for transmitting resistance to this disease. Resistant varieties, such as Cache (7), Relief (5), Hymar, and Wasatch which have been bred, are fairly effective in the control of dwarf smut.

Rodenhiser and Holton (3) found four varieties of the hard red winter wheat group to be resistant to the known races of the ordinary smut. These are Oro × Turkey-Florence (C.I. 11865), Rex × Oro (C.I. 12421), Rex × Rio (C. I. 12234), and Rio × Rex (C.I. 12422). H-44 × Minturki[2] (C.I. 12414) is resistant to all except the two new races of *Tilletia caries* (*T. tritici*), T-15 and T-16, identified from Idaho and West Virginia, respectively. The variety is intermediate in reaction to these. Among the hard red spring wheats are five varieties resistant to all known races, namely, Hope, Komar × Hussar (C.I. 11715), Regent × Pilot (C.I. 12317), Reliance-1018 × Mercury (C.I. 12204), and Renown. *Triticum timopheevi* is another source of resistance, as it appears to be immune to all races. Fertile selections from crosses with *T. timopheevi*, however, have been susceptible to some races of ordinary smut. A number have been susceptible to dwarf smut.

QUALITY

Milling and baking characteristics have been determined on the varieties and strains grown in both the field plot and rod-row trials and these are compared with those obtained on three spring wheats

grown in plot tests during the same period and at the two stations, St. Paul and Waseca, Minn. The results are given in Table 1.

Tests were made on each variety grown in plot trials from each of the two stations, University Farm and Waseca, in Minnesota and on the material grown in the nursery trials from a composite sample of grain made up of equal amounts of seed, if available from each of the two stations.

A number of the strains of winter wheat tested in both the plots and nursery trials appear equal or superior to Minturki in milling and baking characteristics. Minturki has been particularly unsatisfactory to the trade because of the yellowish color of the crumb of the bread. Most of these strains have a whiter crumb color than does Minturki.

In summarizing, it may be seen that many of the hybrid strains of winter wheat are equal to Minturki, Marmin, and Minhardi in winterhardiness, and in addition, equal to or superior to them and to three spring wheats in leaf and stem rust resistance, yield, and in crumb color of bread.

SUMMARY

A large number of strains have been selected from crosses of winter wheats with either Hope or H-44 (spring wheats). These have been tested in the plot and nursery trials at St. Paul and Waseca, Minn., for their winterhardiness, disease resistance, and milling and baking characteristics. Data from these trials are presented, and in addition data are given on three spring wheats for comparison.

Cold resistance tests were made on these strains by growing them in the greenhouse and freezing in low temperature chambers.

Correlation coefficients calculated for winter injury in the field versus cold resistance, as determined by the artificial freezing in cold chambers, were low. It may be that all these strains are equally cold resistant or perhaps the field test does not always bring out true differences in cold resistance.

Strains have been obtained from these crosses and backcrosses that are relatively satisfactory in yield, winterhardiness, leaf and stem rust resistance, and in milling and baking characteristics.

A number of the strains produced from the winter wheat crosses and backcrosses are equal to or superior to three spring wheats in yield, leaf and stem rust resistance, and in certain quality characters.

In Montana, progress is being made in the breeding of hardy winter wheats that are resistant both to dwarf and ordinary smut.

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Technical Cooperation in Small Grain Improvement[1]

B. B. Bayles[2]

THE classical research which produced Marquis wheat was largely the work of one man—Dr. C. E. Saunders. From the unselected mass of segregating material left by his predecessor, who had made the cross, Saunders selected lines with desirable plant characters and later chewed some of the grain of each line to determine which had the best quality of gluten. Thus, we credit Marquis to the work of one individual—an agronomist or plant breeder who also considered disease and quality problems. There were, of course, pathologists and cereal chemists in those days, but they were engaged in other than breeding problems. Many other examples of the research conducted 25 to 40 years ago could be cited to illustrate the general tendency for independent work in very closely related fields.

With increased support for research and a great increase in the mass of accumulated information, research workers have become more and more narrowly specialized. At the same time, the problems to be solved have become more complex and the requirements to be met more exacting. Instead of one cerealist such as Doctor Saunders to plan and conduct a breeding program on a major crop, it is now necessary, or at least very desirable, for several specialists and often for several research agencies to cooperate in order to carry the program out most efficiently. For example, some 30 plant breeders, agronomists, pathologists, entomologists, and cereal chemists representing five state experiment stations and three federal bureaus cooperated in the development of the new hard red winter wheat varieties, Pawnee, Comanche, and Wichita. These varieties, each approved and released by three or more state experiment stations, are increasing very rapidly in the region.

The coordinated programs for the improvement of the small grains, wheat, oats, barley, and rice, are examples of the integration of the knowledge, skill, and resources of technicians in the fields of plant breeding, agronomy, pathology, cytogenetics, entomology, cereal chemistry, and physiology from state, federal, and private agencies. It should be helpful to consider some of the problems encountered in these programs and some of the procedures that have proved useful in promoting efficiency and harmony among the workers and the agencies that they represent. It should not be implied that cooperation is limited to the small grain programs nor that cooperation on these programs is perfect, but they do present an opportunity to discuss some of the problems and some of the advantages as well as the difficulties encountered in carrying out coordinated programs.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Also presented at the annual meeting of the American Society of Agronomy held in Omaha, Neb., Nov. 19 to 22, 1946. Received for publication December 3, 1946.

[2]Principal Agronomist.

The present degree of coordination in the small grain programs has been developed through many years of cooperation between the state agricultural experiment stations, the Cereal Division, and other public and private agencies. In the beginning the programs at the different stations were independent. Informal exchange of ideas and materials by the individual breeders gradually developed. These informal exchanges have expanded until now groups concerned with similar problems and similar materials have become more or less formally organized.

The national wheat improvement program, in which about 125 state and federal scientists located at some 70 experiment stations are interested, is subdivided into five regional or sub-programs. The program divides rather logically according to the types of wheat and the region where each is grown—into the Hard Red Winter, Hard Red Spring, Durum, and Eastern Soft Winter programs. The fifth regional program includes the Rocky Mountain and Pacific Coast states which grow winter and spring, red and white, soft and hard varieties. The environmental factors that determine the areas where the different types of wheat are grown also determine to a considerable extent the disease, insect, quality, and other problems of primary importance so that problems of wheat improvement and production are somewhat similar within a region. This greatly simplifies coordination of the many technical phases of research.

There is no distinction in these programs between research that is state and that which is federal, except that state funds are used mostly for the more local phases of the program and federal funds for the regional or national phases. The coordinator in each region is a Cereal Division employee since each region includes several states, and many difficulties are avoided by this arrangement.

In each region the major objective is to bring together in adapted varieties resistance to the major diseases, insects, drought, winter injury, lodging, good grain quality, and other desirable characteristics. It is obvious that one man could not plan and conduct all phases of such a program. If programs were undertaken independently on each of these problems, the end result would be the production of several varieties each outstanding with respect to certain characteristics but mediocre or poor in other respects and none well suited for commercial production and utilization.

The procedure and degree of coordination must vary with local conditions, such as the facilities and personnel available at individual stations and for the program as a whole, but certain general principles apply to all and certain conditions must be met if the program is to be successful.

The first essential for cooperation is that the specialists conducting the research in related fields be given an opportunity to become acquainted with all the work being conducted on the problem and thus get an understanding of how their respective segments fit into the proposed project as a whole. In order to avoid misunderstandings there must be a clear recognition of the part each worker will play in the coordinated program. Provision must be made for frequent conferences and discussions by the men who are conducting the research

and for the free exchange of ideas and materials. Conferences do not need to be formal, in fact the most effective cooperation is often developed while going over some phase of the work in the field.

Probably the most prominent feature of each of the coordinated programs is the system of uniformly testing at all stations the new strains that appear outstanding at any of the stations. It must be recognized, however, that uniform tests are simply a convenient mechanism by which new strains or new principles developed in the research phases of the program can be properly evaluated. Uniform tests would be of no value without sound research programs to develop new strains or new scientific principles that warrant testing. Usually 20 to 30 of the most promising new strains developed in the breeding programs in a region and a limited number of standard varieties are grown in uniform tests at each cooperating station. Each cooperator may nominate strains for these tests. Observations are recorded on reaction to the diseases present, stiffness of straw, time of maturity, winter survival, yield, and many other characters. The grain is sent to the regional quality laboratory for testing. At the end of the season all data from the several cooperating stations are summarized and made available to the cooperators. More is learned in a single year about the adaptation, disease reaction, quality, and other characteristics of a new variety grown in these tests than can be learned by testing it at a single station for several years.

The arrangement also provides an opportunity for each station to become acquainted with the most promising strains that might be adapted in the region and to know their limits of adaptation before they are released in nearby states. Also, it is often possible for two or more states to agree on simultaneous approval and release of a single strain rather than for each state to release different but similar strains.

Plans must be made to avoid undesirable duplication of research, but even more important, provision must be made for careful planning and full discussion to insure that essential parts of a well-rounded research program will not be omitted. It is basically important that all workers have a part in making these plans.

Tests to obtain information on the reaction of breeding materials to individual races of diseases and to insects like the hessian fly, or on winterhardiness and quality, require facilities, personnel, or environmental conditions that are not available at many breeding stations. It is often more economical and satisfactory to arrange for the testing of a reasonable amount of breeding material from each of several stations at a single location than to provide personnel and facilities at each breeding station. Many such arrangements have been made in each of the coordinated small grain programs. A cooperative project at Pullman, Wash., for example, is responsible for keeping abreast of the distribution and prevalence of races of stinking smut of wheat and of the smuts of oats. Much basic work on the origin and genetics of races has provided background for rendering valuable assistance to wheat and oat breeders. Inoculum of individual races has been furnished to other workers for special studies and many new promising strains, which have shown resistance in local tests, have

been tested to determine their reaction to each of the races individually. The information from a single carefully planned and conducted test to determine the reaction of a wheat to each of the races of bunt is much more useful in predicting the future of that variety under farm conditions or in determining what variety to use as a parent in a breeding program than would be the results from many tests where mass inoculum of unknown races was used. Similar arrangements have also been made to provide the basic pathologic information and pure inoculum in connection with breeding for resistance to major diseases of each of the small grains.

The inclusion of resistance to hessian fly as a major objective in the soft red winter and hard red winter regional programs has been greatly facilitated by arrangements with entomologists in Indiana and Kansas who, in addition to the purely entomological studies, have given attention to the development of satisfactory techniques for testing the reaction of wheat varieties to the different strains of hessian fly and have, each year, tested a considerable amount of material from the breeding programs.

In each of the regional winter wheat, oat, and barley programs arrangements have been made for growing special nurseries at stations where differential winterkilling occurs most every year to determine the relative winterhardiness of new material from all breeders in the region. By this arrangement breeders obtain information on relative winterhardiness of new strains every year, while if they had to depend on differential killing only at their local station they might have to wait several years.

Probably the most difficult to measure of all characters that must be considered in a wheat breeding program is quality. Not only is it difficult to measure and interpret quality characteristics, but the tests are time-consuming and the equipment necessary for making them is expensive. Most stations have not found it possible to install quality laboratories but have depended entirely on cooperative regional laboratories for this information. Because tests to determine quality are among the most expensive and difficult to make, it has been necessary, for the most part, for the laboratories to limit them to those strains that have been shown to be satisfactory in other respects. A laboratory at Manhattan, Kan. in cooperation with the Kansas and other agricultural experiment stations, conducts the quality testing for all stations in the hard red winter program; one at Wooster, Ohio, for the soft winter program; and one at Beltsville, Md., for the hard red spring, durum, and western regional programs. A new one is now being established at Pullman, Wash., to take over the quality work for the western program.

Each of the established laboratories has worked closely with cereal chemists from the trade in the development of techniques for measuring quality characteristics in order to be certain that the evaluation of varieties is in accord with commercial usage. As rapidly as facilities allow the laboratories evaluate materials from the breeding programs.

In addition to the close contact with the commercial cereal chemists in working out methods for making quality tests in the experimental

laboratories it has been found highly desirable to work out arrangements whereby new wheat varieties about to be released are actually milled and baked in the laboratories of commercial concerns or put through pilot tests in larger quantities. For example, the Northwest Crop Improvement Association has regularly grown new varieties of hard red spring wheat and has made arrangements for testing them in commercial laboratories and for milling and baking 60-bushel lots before they are released to farmers. This procedure has not only aided in correlating results from state and federal laboratories with those from the commercial laboratories, but also has served a very useful purpose in acquainting millers and bakers with the characteristics to be encountered in new varieties before they are received in volume on the market. Probably of equal importance has been the psychological effect on members of the trade of having been consulted before the final decision to distribute a variety has been made. Conversely, plant breeders are enabled to become more familiar with commercial problems.

Very satisfactory cooperation has also been developed for testing new varieties of barley for malting quality. A laboratory, cooperative with the Wisconsin Agricultural Experiment Station, the Cereal Division, and the Malt Research Institute, an organization of commercial maltsters, was set up at Madison, Wis. State experiment stations in the barley-growing areas cooperate in growing samples of certain standard varieties and of promising new strains. This laboratory works closely with laboratories in commercial malt houses and breweries to develop satisfactory procedures for measuring the value of varieties in terms of commercial usage. The Malt Research Institute has also been very helpful in making arrangements for the testing in commercial plants of new varieties of barley before their release to farmers. For these tests a standard variety and the new variety under study are grown on a field scale under as nearly similar conditions as possible. Each variety is handled separately through the malt house and brewery and the end product, beer, is sampled by a large group of individuals who rate the samples.

Close cooperation with the extension services and with crop improvement associations is essential in presenting information on new improved varieties to growers and for the rapid increase and distribution of seed. Consideration should also be given to kernel characteristics used in grading grain on the market to insure that new varieties do not further confuse a most difficult problem. For example, a new hard red winter wheat variety with grain that cannot be distinguished from hard red spring varieties makes accurate grading of samples almost impossible.

It must be clearly recognized that coordination is only a small part of any program for the development of improved varieties. It is merely the mechanism for testing, integrating, and applying the results obtained in the research programs of the individual specialists, and the mechanics of coordination must not become a burden on research. One of the tragedies of too rigid coordination is the stifling of individual research, which is essential to any successful breeding program. The organization then of the coordinated program must be

such that every research specialist will devote only a small part of his time to servicing the coordinated program and a major part to fundamental and applied research in his chosen field. If the basic research is not productive, there is nothing to coordinate.

Because of the need, during the war period, to devote the limited personnel available to those activities that would give immediate returns in increased food and feed production many accomplishments are now in danger of being lost as a result of insufficient basic information in pathology, genetics, physiology, entomology, cereal technology, or other fields of science.

It is not sufficient that the pathologist simply inoculate plant selections with mass inoculum of an organism to determine their resistance to a disease. He must know the life history of the organism, techniques for inoculation, effect on the host plant, physiologic specialization of the organism, geographic distribution of races, reaction of varieties to each race, and many other facts necessary to plan intelligently and to conduct pathologic phases of the improvement program. It is necessary that he know of new diseases and of new races of old diseases and something of the reaction of different varieties to them as insurance against the time when they may become important. The pythium disease of sorghum, for example, never became a serious menace because plant breeders were ready for it before it became generally prevalent.

Keeping abreast of potential problems often involves cooperation with workers in foreign countries as, for example, the exchange of materials with pathologists and plant breeders in Peru to obtain information on the reaction of wheat varieties to race 189 of stem rust that is present in that country. This race has been found to attack wheat varieties that are resistant to all races present in the United States and Canada. Through the testing of North American varieties in Peru, varieties that are resistant to this race are now known. This information will prove invaluable in breeding adapted wheats resistant to this race if it should ever appear in this country. When a new variety is released it is much safer to know that it is susceptible to a particular race of a disease and to begin immediately breeding new varieties resistant to this race before it becomes widely prevalent than to wait for farmers to report that the variety is heavily infected with the disease on their farms.

The effect of the inadequate support during the war period for the basic research which provides the foundation for the improvement programs cannot be over emphasized. Many weaknesses in present improvement programs can be laid directly to inadequate basic information on the insect or disease organism against which resistance is being sought and to inadequate knowledge of the interrelationships of parasite and host and of the effect of environmental factors on them.

The second largest oat crop ever produced in this country was harvested in 1946. No small part of the credit for this is due to the large acreage of the varieties selected from the Victoria-Richland cross which produced very high yields even though they were injured by the new helminthosporium disease. If support had been sufficient

to allow adequate pathologic research to be pursued at the same time that major efforts were being given to getting the best selections from the Victoria-Richland cross tested and into commercial production, the situation would be less serious. Similarly, the program of breeding corn hybrids resistant to the European corn borer is seriously handicapped because of inadequate basic information on the plant-insect relationships.

When the regional wheat quality laboratories were organized several years ago it was agreed that the amount of service work that the cereal chemists should be asked to perform for the plant breeders should be limited so that attention could be given to research that would give an understanding of what constituted quality for different classes and varieties of wheat and for the development of techniques for measuring the characteristics that determine quality. Because cereal chemists spent a considerable portion of their time on basic research they now have a much better understanding of the influence of different grain characteristics on the quality of baked products, and they have developed new and improved techniques for evaluating the quality of varieties. The need for all specialists participating in coordinated improvement programs to have time and facilities for basic research in their specialized fields must be constantly kept in mind.

Looking ahead, it seems certain that research programs will be more closely coordinated on a regional or national basis than they have been in the past. The Research and Marketing Act of 1946 recognized this need by specifying that portions of the funds allotted to states must be spent for projects on which two or more states would cooperate and provide for federal participation in the coordination. The increased volume of research, the greater complexity of the problems under investigation, and the more exacting objectives to be attained all require coordination if funds are to be efficiently used. With the start that has already been made in working out responsibilities of the state experiment stations, the Cereal Division, and other public and private agencies, it should not be difficult to develop coordination of the cereal improvement and research programs further on a sound and efficient basis that will prove satisfactory to all concerned.

The Production of Forage Crop Mixtures Under Different Systems of Management, the Consequent Effect on Corn Yields, and the Re-establishment of Alfalfa[1]

C. M. HARRISON, H. M. BROWN, AND H.C. RATHER[2]

FORAGE grasses and legumes either alone or in mixture have contributed a major share in the feeding of the nation's livestock, functioned as green manure crops to the advantage of the cash crops which follow in rotation, had a desirable influence on the physical condition of the soil, and aided in the protection of the soil against destructive erosion and leaching losses. When legumes are grown alone or in association with the grasses, additional benefits accrue from the activities of the nitrogen-fixing bacteria associated with the legumes.

The growing of grasses and legumes, alone or in combination, has long been considered as an essential part of a good crop rotation, but varied management and uses to which the forage crop is put, once it is established, does not assure a uniformly beneficial response on the part of cultivated crops which follow. The continued harvest of a forage for hay involves the removal of large quantities of plant nutrients from the soil. Unless large quantities of manure and commercial fertilizer are returned to replenish the soil with nutrients, its productivity may be seriously curtailed by forage crop production. The nature of the forage crop and whether it is used entirely as a green manure crop or removed as pasture or hay may have a decided effect on land management practices.

PLAN OF EXPERIMENT

In order to study the productivity of different forage crop mixtures under different systems of management and the resulting influence of forage use on soil productivity, an experiment was laid out at the Michigan Agricultural Experiment Station in 1938. Four different forage mixtures, one straight grass, one straight legume, and two consisting of both grasses and legumes, were made up as follows: (1) Timothy, Kentucky bluegrass, red clover, alsike clover, and white clover; (2) timothy, smooth bromegrass, perennial ryegrass, Kentucky bluegrass, and Canada bluegrass, (3) alfalfa, smooth bromegrass, red clover, alsike clover, and white clover, and (4) alfalfa, red clover, alsike clover, and white clover.

There were 12 square plots, each 1/24 acre in size, seeded to each mixture. Three systems of management were provided for each of the four mixtures as follows: (a) Hay harvest only, with one or two cuttings per season depending upon productive nature of the mixture; (b) hay harvest of the first cutting, with pasture of the subsequent growth; (C) pasture only.

This system allowed for four randomized blocks with each management practice being replicated four times on each of the four different mixtures.

In all cases where pasturing was carried on, grazing was discontinued on September 1 to give the plants ample opportunity for fall storage of root reserves.

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[1]Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 845 N.S. Received for publication November 4, 1946.

[2]Professor, Assistant Professor, and former Head of the Farm Crops Department, now Dean of the Basic College, respectively.

Sheep were used as grazing animals and were confined to the plots by means of a square, portable paddock which enclosed the entire 1/24 acre.

The land was a moderately sloping Conover clay loam soil. The entire area was fertilized with 400 pounds per acre of 0–20–20 fertilizer and the seedings were made in early August of 1938 without a grain companion crop. All of the seedings were successfully established and pasturing was started in May of 1939.

The three systems of management were carried on over a 3-year period after which the entire area was plowed and planted to corn. Following the corn, one-half of each original plot was refertilized with 400 pounds of 0–20–20, the half remaining received no fertilizer and the entire area reseeded to alfalfa in small grain.

RESULTS

PRODUCTION OF FORAGE CROP MIXTURES

The various mixtures were observed and changes in botanical composition were recorded in addition to securing yield data and grazing information from the four mixtures under the three systems of management. Table 1 indicates the general changes which occurred in the composition of the original mixtures over a 3-year period.

TABLE 1.—*Changes in original mixtures occurring over a 3-year period.**

Year	Changes observed
	Mixture I: Grass-clover
1938	Original seeding: Timothy, red clover, alsike, white clover, Kentucky bluegrass
1939	Mostly red and alsike clover with light timothy mixture; good clove aftermath
1940	Timothy and bluegrass; clover insignificant
1941	Timothy and bluegrass with slight trace of volunteer alsike
	Mixture II: Straight Grass
1938	Original seeding: Timothy, bromegrass, ryegrass, Kentucky and Canada bluegrass
1939	A vigorous mixture of above grasses
1940	Largely Kentucky bluegrass; some timothy and bromegrass
1941	Almost straight Kentucky bluegrass; light amount of bromegrass, much less vigorous than where grown with alfalfa
	Mixture III: Alfalfa-Clover-Smooth Bromegrass
1938	Original seeding: Smooth bromegrass, alfalfa, red clover, alsike, white clover
1939	Predominantly alfalfa and bromegrass; light red and alsike clover in mixture
1940	Alfalfa and bromegrass
1941	Alfalfa and increasing amount of bromegrass especially in pastured plots
	Mixture IV: Straight Legume
1938	Original seeding: Alfalfa, red clover, alsike, white clover
1939	Alfalfa with light clover mixture
1940	Straight alfalfa
1941	Alfalfa, Canada bluegrass and weeds; the alfalfa had winterkilled rather badly in several plots

*Mixtures seeded in August 1938, with 400 pounds an acre of 0–20–20 fertilizer.

Table 2 shows the returns from the pasturing of the four mixtures which are recorded over the 3-year period in terms of sheep days per acre. Weight gains are recorded for one year, 1940, as only during

this year were the animals young enough and in such condition as to put on normal gains. During the other two years, yearlings instead of lambs were used and the pastures provided more maintenance than gain in liveweight.

TABLE 2.—*Returns from straight pasture, average of four replications.*

Forage mixture	1939, sheep days per acre	1940		1941, sheep days per acre	Total 3 years sheep days per acre
		Sheep days per acre	Gain in lbs. per acre		
I	1,200	954	170	348	2,502
II	1,218	996	141	348	2,562
III	1,812	2,112	262	1,296	5,220
IV	1,812	2,256	311	1,296	5,364

It will be noted that there is considerable difference in the sheep days per acre, depending upon the type of mixture grazed. This was largely due to two factors, namely, the inherent productivity of the various mixtures, and their drouth resistance which made possible a longer grazing season with mixtures III and IV when compared to I and II. This was particularly noticeable during 1941 when a dry period, extending over much of the season, cut the grazing season of all mixtures and affected mixtures I and II more than III and IV. The weight gains are comparative, although they may appear somewhat low. Difficulties encountered in confining, weighing, and moving the animals at periodic intervals interfered somewhat with normal gains in weight.

In the second system of management where the first crop was cut for hay and the second crop pastured by sheep, the hay yields were determined by cutting a swath 6 feet wide and 42.5 feet long through the center of each plot. The green material was weighed, a sample taken for moisture determination, and the yields converted to hay at 15% moisture. The results are shown in Table 3.

TABLE 3.—*Hay yields in pounds per acre at 15% moisture and pasture returns measured in sheep days per acre from plots where the first cutting only was taken for hay and the second growth used as pasture, average of four replications.*

Forage mixture	1939		1940		1941		Total	
	Hay, lbs. per acre	Sheep days per acre	Hay, lbs. per acre	Sheep days per acre	Hay, lbs. per acre	Sheep days per acre	Hay, lbs. per acre	Sheep days per acre
I	3,344	342	3,613	306	2,122	180	9,079	828
II	3,617	342	2,000	252	2,596	180	8,213	774
III	4,440	990	4,921	684	5,342	384	14,703	2,058
IV	3,351	990	4,446	648	3,892	384	11,689	2,022

It should be noted in Table 3 that differences in yielding ability of the various mixtures are not only apparent in terms of hay produced

but also in grazing days in the second crop season which reflect the drouth-resisting qualities of the plants making up the mixtures.

The third system of management in which both cuttings, where available, were removed from the plots as hay was undertaken in an attempt to show the inherent yielding ability of the four mixtures under test and also the effect of such removal on the yield of corn and alfalfa to follow in the rotation.

Table 4 shows the results from each of the 3 years and the total production removed in terms of hay at 15% moisture. It should be noted that mixtures III and IV not only produced approximately twice as much hay per acre over the 3-year period, but that mixtures I and II failed to produce sufficient harvestable second growth to warrant cutting in 2 of the 3 years.

TABLE 4.—*Returns from plots harvested only for hay, taking two cuttings per season, if available, average of four replications.*

Forage mixture	Cutting	Hay yield, lbs. per acre at 15% moisture			
		1939	1940	1941	Total
I	1st	2,804	3,213	2,719	
	2nd	1,304	None	None	
	Total	4,108	3,213	2,719	10,040
II	1st	3,764	2,313	2,728	
	2nd	309	None	None	
	Total	4,073	2,313	2,728	9,114
III	1st	4,440	4,758	6,619	
	2nd	2,413	2,693	263	
	Total	6,853	7,451	6,882	21,186
IV	1st	4,394	3,974	4,206	
	2nd	2,835	3,360	205	
	Total	7,229	7,334	4,411	18,974

EFFECT ON CORN YIELDS

Following the 3 years of variable forage management, the entire area was spring plowed and fitted for corn. No commercial fertilizer or manure was added to the area and an adapted hybrid was planted on May 20, 1942. The original plots were restaked prior to harvest and silage and grain yields were secured on September 22 and October 7, respectively. Moisture determinations were made on the ears at grain harvest time to assist in yield calculations and to determine any differences in maturity that might have been caused by the previous forage management. Table 5 shows the silage, grain, and moisture relationships of corn harvested from the original forage plots.

As a consequence of the limited number of replications and the variation recorded in the yields of the replications caused by drain-

TABLE 5.—*Corn yields in 1942, following 3 years of growing four forage mixtures under three systems of management, average of four replications.*

Forage mixture	Management	Silage Sept. 22, tons per acre, green weight	Moisture content of grain, Oct. 7, %	Grain yield Oct. 7 in bus. per acre at 15.5% moisture
I	Pasture	9.7	36.9	71.8
	Hay and pasture	8.7	40.4	62.6
	Hay	8.4	41.6	59.5
II	Pasture	10.7	37.9	71.9
	Hay and pasture	7.8	40.6	57.5
	Hay	9.0	40.8	61.2
III	Pasture	10.7	37.2	80.3
	Hay and pasture	9.2	40.5	62.9
	Hay	11.1	39.7	72.8
IV	Pasture	11.4	38.4	80.1
	Hay and pasture	10.3	41.2	72.4
	Hay	8.3	40.0	66.3

Differences necessary for significance:

	5% level	1% level
Silage	2.2 tons	3.0 tons
Moisture	4.0%	5.4%
Grain yield	13.9 bu.	18.6 bu.

age and soil variation, very few of the differences recorded in Table 5 are significant. However, it might be pointed out that the general tendency was for the continuous pasture practice to yield the most silage and grain of the lowest moisture content when compared with the two other forage practices of a given mixture.

In order to show any existing differences in silage and grain yields yields between the four previous mixtures and three previous treatments in the yield of corn, the yields were averaged and compared as to mixture without regard to treatment and, likewise, as to treatment without regard to mixture. These figures are shown in Table 6.

The figures in Table 6 show that the pasture treatment was highly significant in affecting corn yields when compared to continuous hay or the hay-pasture combination. The significance in favor of the pasture treatment of the previous mixtures is apparent in yields of corn silage and grain and in the moisture content of the grain at harvest time. There is no difference between the continuous hay or hay-pasture treatments of the previously grown mixtures.

The differences between mixtures as to their effect on the subsequent yield of corn are not as definite as are the differences between the three different treatments. However, the figures show a significant difference between mixtures I and II when compared with III and IV. The mixtures containing alfalfa show a significant increase in yield of grain over the mixtures not containing alfalfa. There was little, if any, difference between the mixture containing red clover and the straight grass mixture. The differences between the two sets

TABLE 6.—*A comparison of corn yields in 1942 as to forage mixture averages without regard to treatment and treatment without regard to mixture.*

Previous mixture	Mixture averages: Silage, tons	Mixture averages: Grain Bu.	Mixture averages: Grain % moisture	Previous treatment	Treatment averages: Silage, tons	Treatment averages: Grain Bu.	Treatment averages: Grain % moisture
I	8.9	64.7	39.6	Pasture	10.6	76.0	37.6
II	9.2	63.5	39.8	Hay and pasture	9.0	63.8	40.7
III	10.3	72.0	39.1	Hay	9.2	65.0	40.5
IV	10.0	72.9	39.9				

Differences necessary for significance

Item	(a) As to previous mixture: 5% level	(a) As to previous mixture: 1% level	(b) As to previous treatment: 5% level	(b) As to previous treatment: 1% level
Silage........	1.3 tons	1.7 tons	1.1 tons	1.5 tons
Grain........	8.0 bu.	10.7 bu.	7.0 bu.	9.3 bu.
Moisture.....	2.3%	3.1%	2.0%	2.7%

TABLE 7.—*Yields of alfalfa hay at 15% moisture in pounds per acre for 1944 and 1945 as influenced by previous forage mixture, treatment, and additional fertilizer.*

Treatment	Av. yields of hay, lbs. per acre: 1944	1945	Average	Difference in pounds per acre necessary for significance	5% level	1% level
Years						
	3,607	4,389	3,998	Between years	268	235
Previous Mixture						
I.............	3,709	4,676	4,193	In either year	537	711
II.............	3,590	4,372	3,981	In 2-year av.	379	503
III.............	3,700	4,172	3,936			
IV.............	3,430	4,336	3,883			
Previous Forage Treatments						
Pasture.........	4,232	5,020	4,626	In either year	465	616
Hay and pasture	3,230	4,018	3,624	In 2-year av.	329	435
Hay...........	3,359	4,128	3,744			
Fertilizer						
Fertilized.......	4,235	4,721	4,478	In either year	251	333
Unfertilized.....	2,979	4,057	3,518	In 2-year av.	178	235

of mixtures were not as great when comparing silage yields, but the tendency was in the same general direction. There were no differences in maturity as indicated by moisture content of the grain at harvest time.

EFFECT ON RE-ESTABLISHMENT OF ALFALFA

Following the year of corn, the area was fall plowed and the following spring one-half of each of the original plots was refertilized with an additional 400 pounds per acre of 0–20–20 fertilizer and the remaining half of each original plot left without fertilizer to serve as a check on past practices and their influence on reseeding. After the fertilizer was applied to one-half of each of the original plots, a seedbed was prepared and the entire area seeded to alfalfa with an oat companion crop in April, 1943. The oat crop was a failure due to a particularly wet spring followed by a hot dry period during growth and maturity and no oat yields were taken. The seeding establishment was considered satisfactory although not a perfect stand. The distribution of seedling alfalfa plants was regular over the entire area, although lacking somewhat in density.

TABLE 8.—*Comparisons between previous forage treatment and additional fertilizer on the yield of hay following reseeding of original plots.*

Previous treatment	Fertilizer treatment	1944	1945	Yield in lbs. per acae
Pasture	Fertilized	4,561	5,117	4,839
	Unfertilized	3,902	4,923	4,412
	Difference	659	194	427
Hay and pasture	Fertilized	4,056	4,442	4,249
	Unfertilized	2,405	3,594	2,999
	Difference	1,651	848	1,250
Hay	Fertilized	4,088	4,602	4,345
	Unfertilized	2,631	3,653	3,142
	Difference	1,457	949	1,203

Difference necessary for significance:

	5% level	1% level
In 2-year av.	308	408
Either year	435	577

Noticeable differences were apparent even in the seeding year between the vigor of the seedlings on the refertilized portion of the plot and those not refertilized. Likewise, differences were apparent in the unfertilized portions of the various plots which reflected the past treatment of the various forage mixtures originally seeded.

In an attempt to measure the effect of the previous treatment of the original mixture as well as the effect of the additional fertilizer, hay yields were taken during 1944 and 1945. Only first cuttings were removed during these two years because of a shortage of labor and the lack of growth in the second cutting during these two years. Hay yields and moisture percentages were taken from both the refertilized and the "no additional fertilizer" sections of the plots. Samples were taken by cutting a full swath through each half of each plot, weighing the green material, and taking samples for moisture determinations.

TABLE 9.—*Comparison of hay yields as influenced by previous mixture, forage treatment, and fertilizer.*

Previous mixture	Fertilizer treatment	1944			1945			Average		
		Pasture	Hay and pasture	Hay	Pasture	Hay and pasture	Hay	Pasture	Hay and pasture	Hay
I	Fertilized	4,626	4,234	4,075	5,609	4,380	4,910	5,118	4,307	4,492
	Unfertilized	4,086	2,602	2,633	5,508	4,004	3,646	4,797	3,303	3,139
	Difference	540	1,632	1,442	101	376	1,264	321	1,004	1,353
II	Fertilized	3,644	4,443	4,456	5,008	4,694	4,550	4,326	4,568	4,503
	Unfertilized	3,198	3,291	2,506	4,858	4,018	3,102	4,028	3,655	2,804
	Difference	446	1,152	1,950	150	676	1,448	298	913	1,699
III	Fertilized	5,142	3,467	4,466	4,766	4,040	4,733	4,954	3,754	4,600
	Unfertilized	4,404	1,770	2,949	4,620	2,765	4,104	4,512	2,268	3,527
	Difference	738	1,697	1,517	146	1,275	629	442	1,486	1,073
IV	Fertilized	4,835	4,079	3,357	5,086	4,655	4,217	4,960	4,367	3,787
	Unfertilized	3,920	1,956	2,434	4,706	3,589	3,760	4,313	2,772	3,097
	Difference	915	2,123	923	380	1,066	457	647	1,595	690

Difference necessary for significance:

	5% level	1% level
2-year av.	615	815
Either year	870	1,153

The yields are reported in pounds per acre of hay at 15% moisture in Tables 7, 8, and 9. Table 10 gives the analysis of variance for the 2 years.

The differences in yield were highly significant between the previous forage treatments and between fertilizer and no fertilizer (Table 7). There was no significant difference in yields of hay as influenced by the previous mixtures.

There are highly significant differences in the 2-year averages and in either year and these differences are due to previous forage treatments and to fertilizers. (See Table 7.)

There are some highly significant differences in 2-year averages and in either year. These differences are due to differences in forage treatments and fertilizers rather than to mixtures. (See Tables 2, 3, 4, and 5.)

TABLE 10.—*Analysis of variance for the 2 years' data.*

Source	Degrees of freedom	Sums of squares	Mean square	F	S.E.
Replications	3	9,802,896	3,267,632	3.8*	—
Years	1	29,314,846	29,314,846	33.9**	—
Cultures (mixtures and treatments)	11	57,181,078	5,198,280	6.0**	—
Years × cultures	11	8,101,498	736,500	—	—
Error (a)	69	59,613,888	863,969	—	929.5
Fertilizers	1	44,251,201	44,251,201	116.9**	—
Years × fertilizers	1	4,207,760	4,207,760	11.1**	—
Cultures × fertilizers	11	10,736,488	976,044	2.6*	—
Years × cultures × fertilizers	11	1,098,498	99,864	—	—
Error (b)	72	27,263,486	378,660	—	615.4

*Exceeds 5% level of significance.
**Exceeds 1% level of significance.

A study of Tables 7, 8, and 9 shows that the previous forage mixtures had no significant influence on the yield of hay following reseeding but that variations in management of the previous forage and use of additional fertilizer produced highly significant differences. It should be noted that the removal of the original forage mixtures as pasture gave the least increase in hay yield following additional fertilizer and reseeding. Additional fertilizer seemed particularly beneficial in establishing a productive alfalfa stand on those areas from which the forage had been previously removed as either hay or hay and pasture.

The data indicate that there were relatively small differences, if any, between the various mixtures used in their influence on the yields of corn following, but that variations in management resulted in quite wide differences in yields. Likewise, the management practices used on the various mixtures influenced the stand establishment and yield of alfalfa when it was reseeded with and without fertilizer following corn. Establishment and yield was much better

following continuous pasture than was true of either continuous hay, or hay and pasture management practices.

CONCLUSIONS

1. Four different mixtures of legumes and grasses were subjected over a 3-year period to three different systems of management, namely, pastured continuously, first crop cut for hay, second crop pastured, and cut for hay continuously.

2. Gains made by sheep were nearly double in 1 year, and sheep days of grazing were more than doubled during the 3-year period where alfalfa was present in the mixture as compared with the straight grass mixture or the red clover-grass mixture.

3. Yields of hay, under a continuous hay harvest system, were likewise approximately doubled over the 3-year period where alfalfa was present in the mixture in comparison with the straight grass or red clover-grass mixtures.

4. Corn yields either as grain or silage were significantly higher where a given preceding mixture was pastured rather than cut for hay or used for hay and pasture both.

5. The differences among mixtures in respect to their effect on the subsequent yield of corn were not as definite as were the differences among treatments.

6. The mixtures containing alfalfa show a significant increase in yield of grain over the mixtures not containing alfalfa.

7. The kind of mixture had little, if any, effect on the yield of hay following reseeding.

8. Previous management and additional fertilizer each were highly significant in affecting the yield of alfalfa after reseeding.

Insect Pollination in Guayule, *Parthenium Argentatum* Gray[1]

ELDON J. GARDNER[2]

CROSS pollination is known to occur in nature in most strains of guayule, *Parthenium argentatum* Gray, which have been studied (2, 3, 4, 5, 6, 9, 11, 12,).[3] Natural agents of pollination are of interest and have a practical significance in the guayule breeding program. Insects and wind are the two most likely transporting agents. The efficiency of the wind as a pollen carrier at Salinas, Calif., and the effectiveness of wind-borne pollen in fertilization were discussed in a previous article (4). Observations concerning insect pollination are reported in this paper.

Numerous insects inhabit the guayule fields during the flowering season some of which become intimately associated with the pollen-producing parts of the plant. The adhesiveness of the pollen and the spiny character of the outer surface of the grains suggest an adaptation to insect transportation. The role of insects as agents of pollination in guayule has been a subject for speculation, but little experimental work has been done on the problem. There is reason to suspect that insects may be an important natural agent in cross pollination. Noncontrolled crosses among different strains of guayule, which occur readily in the field, and interspecific crosses which Rollins (12) has shown also to occur in nature may be dependent to a large extent on insect pollination.

A more practical reason for pursuing the problem of insect pollination at this time lies in the possibility of utilizing insects for making experimental crosses. Hand pollination is a tedious, time-consuming task. With the development of self-sterile strains of guayule possessing characters desirable in the breeding program, the prospect of working out a technique whereby insects can be transferred from one cage to another and thus affect pollination stimulates much interest. Kalashnikov (5) attempted such a procedure by introducing ants into paper bag isolators. He reported that this method does not lead to as high a percentage of seed set as hand pollination with a brush.

MATERIALS AND METHODS

Large numbers of insects were collected in the guayule fields and subjected to microscopic inspection for pollen. Guayule pollen was distinguished morphologically from other kinds. A staining technique (10) making use of cotton blue lactophenol, as given by Lee (7), was employed to determine whether the insect-borne pollen was normal or consisted of aborted and unfilled grains. When it became obvious that insects associated with the plants were carrying pollen which appear-

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[3]Figures in parenthesis refer to "Literature Cited", p. 232.

ed to be good, the next step was to study the importance of insects as natural agents of pollination and to determine whether or not it would be feasible to use insects for experimental cross-pollination. Both field and greenhouse experiments were devised to study these problems.

FIELD STUDY

Field experiments were conducted during the summer of 1945 to determine the effectiveness of insects as pollen carriers. Cheesecloth cages placed around the plants were used to hold the insects and isolate the plants from wind-borne pollen. The experiments were well designed and carefully conducted, but the checks showed a high percentage germination. This indicated that the cheesecloth bags were not effective isolators for guayule pollen and the experimental results were thus confounded. The data were discarded and the experiments were repeated during the next season. The problem of effective isolation for plants being selfed and crossed has since been investigated and the results are reported in another article (4). Kraft paper and percale bags were used in the experiments reported here.

Self-sterile 36+ chromosome plants from Powers' (8) seed collection (accession 4255) were used for the experiments. All showed the yellow color indicating that they were homozygous for the recessive factor, xanthous. Each plant had been selfed and none produced more than 1% germination of seed, thus demonstrating the high degree of self-sterility inherent in the selection. The plants were randomized in four replications with provision for seven different treatments. Six plants in each replicate were covered with percale bags supported in the center with metal stakes and tied at the top and bottom (Fig. 1) 1 week before the introduction of the insects. The mature flowers were picked and only those which were at or approaching the receptive stage were present on the plant when the insects were introduced. One plant in each replicate was left uncovered as a check and allowed to be pollinated in the natural way. One covered plant in each replicate was reserved to check the effectiveness of the isolation and no insects were introduced.

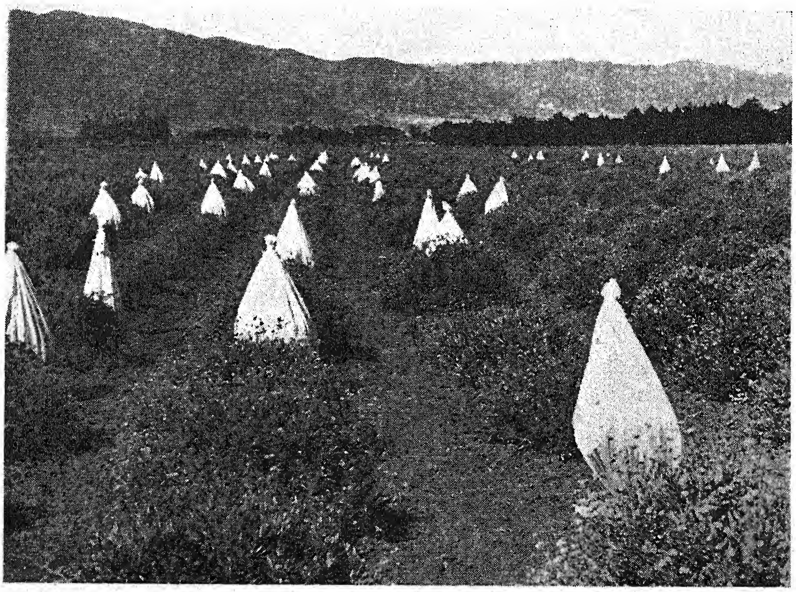

FIG. 1.—Guayule field showing cloth cages placed around yellow plants for insect pollination experiments.

The insects which were most abundant in the guayule fields were used in the experiments. Ladybird beetles, mostly *Hippodemia convergens* Guerin, were numerous at the time the experiments were begun. Counts made on 20 plants chosen at random showed an average of 26 ladybird beetles per plant. Not only were these beetles present in abundance, but they were intimately associated with the flowers. During the warm part of the day they were observed to fly actively from one plant to another. Small black flies, *Hylemya* spp. Robineau-Desvoidy, were also abundant. The season was early for lygus bugs, *Lygus hesperus* Knight, but they were present in appreciable numbers. Romney, *et al.* (13) reported that lygus represented 64% of the total insect population on guayule in the Salinas and Bakersfield areas in the 1943 season. Western 12-spotted cucumber beetles, *Diabrotica sorro* Lec., were also present in appreciable numbers. These four insects seemed to be dominant and universal guayule insects which could be expected to carry pollen from one plant to another if any insects do.

Insects for the first series of field experiments were collected in nets from the guayule fields. Microscopic inspection showed that all carried guayule pollen on their bodies. The insects were removed from the nets in sterile pipettes and introduced into bags surrounding plants through temporary openings near the bottom. Every precaution was taken to avoid mechanical transfer of pollen. Each insect species collected in the fields was introduced into the cages surrounding one plant in each replicate in the following numbers: 100 ladybird beetles, 100 flies, 50 lygus bugs, and 50 cucumber beetles. One hundred ladybird beetles collected elsewhere and observed not to carry guayule pollen were introduced into the cages surrounding each of four other plants as checks. The insects were allowed to remain with the plants 7 days. Pollen had been shown in a previous study (4) to be viable under field conditions for that long a period. The immature flowers and buds were picked at that time. The bags were allowed to remain on the plants until the flowers which were in a receptive stage while the insects were present had dried up. When the seed was mature it was picked, treated by the method described by Benedict and Robinson (1), and 500 seeds from each plant were sown in soil in the greenhouse.

The other part of the field study was designed to follow more accurately the transfer of pollen by insects. Ladybird beetles were collected from another location some distance from any guayule. Microscopic examination showed these insects to be free from guayule pollen. One hundred were placed in the cages surrounding each of four self-sterile plants as a check and allowed to remain for the same length of time as those carrying pollen. About 500 beetles were placed in a cage surrounding a large, yellow plant, homozygous for the color factor (xanthous). This plant was producing an abundance of pollen. The insects were allowed to remain 48 hours and 100 were transferred to each of four other yellow plants, also homozygous for the color factor. Sterile pipettes were used in making the transfers and the insects were allowed to crawl into the cages from a temporary opening near the bottom. Every precaution was taken to avoid mechanical transfer of pollen. It was expected that the proportion of seeds which germinated would indicate the effectiveness of pollen transfer by the insects. All progeny should be yellow if the isolation was complete.

Another 500 beetles were placed in a cage with a large green plant presumed to be homozygous for the dominant green color factor. The insects were allowed to remain for the same length of time and transferred in the same manner described above to four other yellow plants. All progeny from these crosses, except the few resulting from natural selfing of the seed parent, should be green. The seeds (500 seeds from each plant) were picked, treated, and germinated as described above.

GREENHOUSE STUDY

Cages built on a wooden frame 10 inches square and 14 inches high, each constructed with one side of glass and three sides of fine silk (Fig. 2) were used in the first series of greenhouse experiments. The silk was removed from one side of each cage and the cages were joined together in pairs with the open sides facing each other. The plants were selected from a self-sterile, 36+ chromosome strain (Powers' 4255 (8)) on the basis of uniformity in size and numbers of flower heads. They were about 6 months old at the time the experiments were begun. The plants were placed inside the cages before the flowers matured and were not removed until the seed was picked.

There was no possibility of direct contact between the members of each pair of

plants in the cages. Since guayule pollen is heavy it was presumed that it would not move any great distance in the air of the cages in the absence of wind. Micro slides smeared with glycerine were placed in the cages and allowed to remain several days before the experiments were begun. Microscopic inspection showed that no pollen penetrated the cages under greenhouse conditions. The experiment was conducted in a protected section of the greenhouse and every effort was made to avoid drafts during the critical period. The insects were introduced with a glass pipette through a temporary opening in the side of one of the cages in each pair. They could move freely from one compartment to another, and it was presumed that they would be responsible for all pollen transported back and forth from one member of the pair of plants to the other.

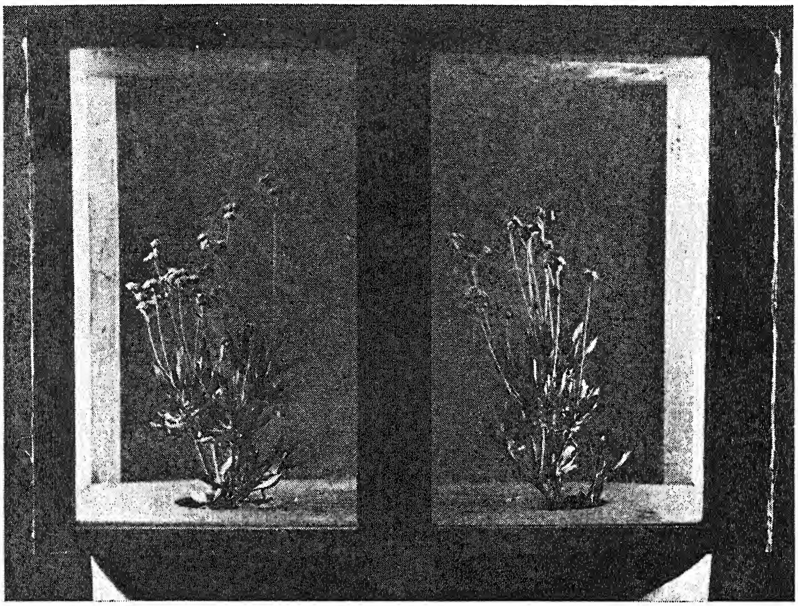

FIG. 2.—Plants in small cages prepared for insect pollination experiments in the greenhouse.

The insects used in the experiment were collected from fields and secured from laboratories widely separated from guayule. Ladybird beetles and cucumber beetles were collected from a chard field west of Salinas, Calif., thrips, *Thrips tabaci* Lin., were collected in an onion field adjoining the chard field and the two species of fruit flies, *Drosophila melanogaster* Meigen and *D. hydei* Sturtevant, were obtained through the courtesy of Dr. Everett Dempster, Department of Genetics, University of California.

The pairs of cages containing plants were identified alphabetically from A to F. The A pair was reserved as a check and no insects were introduced. Twenty-five ladybird beetles were introduced into the B cages, 50 fruit flies, *D. melanogaster*, into the C cages, 50 fruit flies, *D. hydei*, into the D cages, 25 cucumber beetles into the E cages, and at least 50 thrips were introduced into the F cages. The insects were allowed to remain in the cages 1 week. At the end of that period all plants were dusted with 5% DDT without opening the cages. When the seed was mature, it was picked, treated (as above), and germinated between blotters in the germinator.

Since selfing cages considerably larger than those described above were being used in greenhouse studies on guayule an experiment was designed to determine whether or not insects could be used for transferring pollen from one plant to

another in these cages in place of the usual method of brushing. The cages were 24 inches square and 36 inches high. They were constructed on wooden frames and covered with cheesecloth (Fig. 3). Appropriate tests had shown them to be suitable for isolating plants from foreign pollen in the greenhouse. Ladybird beetles free from guayule pollen were used in the experiments because they had been shown to carry guayule pollen from one plant to another in the field and in other greenhouse experiments and they caused no injury to the plants. Plants which had been crossed before and were known to be compatible were used for the experimental crosses. Six pairs were placed in cages, as shown in Fig. 3. Two pairs were brushed

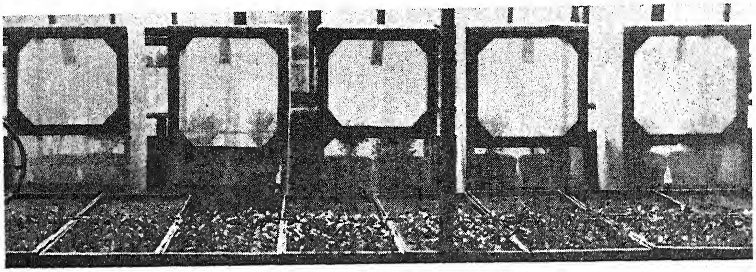

FIG. 3.—Large cages containing pairs of plants used in insect pollination experiments.

daily, the pollen from one member of each pair being transferred to the other and *vice versa* with a camel hair brush. At least 50 ladybird beetles were maintained in each of two other cages. Fresh beetles were introduced at three different times during the 3 weeks period. The other two pairs of caged plants were reserved as checks. At the end of the 3-weeks period all plants were dusted with 5% DDT, and all immature flowers and buds were removed. The plants were kept in the cages until the seed was mature. The seed was picked, treated, and germinated by the method described above for other greenhouse experiments.

EXPERIMENTAL RESULTS

FIELD STUDY

All insects collected in the guayule fields during the flowering season and subjected to microscopic examination were observed to be carrying some guayule pollen on their bodies. Pollen grains washed off the bodies of captured insects accepted the cytoplasmic stain (cotton blue lactophenol) uniformly and appeared to represent normal pollen. The proportion of aborted grains was not greater than that reported for samples taken directly from the experimental plots in a previous study (10).

Anatomical features and habits of the insects seemed to determine largely the amount of pollen carried. Insects which associate themselves intimately with the flowers and possess deep sutures on their ventral surfaces were observed to carry an abundance of pollen. Considerable variation in quantity was observed by microscopic inspection of insects collected in the guayule fields. Flies, *Hylemya* spp., were found to carry an average of about 50 pollen grains each. Lygus bugs, *L. hesperus*, carried an average of nearly 500 grains each. As a part of one field observation two ladybird beetles, *H. convergens*, were induced to walk through separate drops of cotton blue stain on a glass micro slide. One left 180 and the other 164 guayule pollen grains

on the stain. This pollen was washed from the legs and the ventral surfaces of the beetles. The same two insects were then dipped successively in several drops of stain. An appreciable amount of pollen was left in each drop. At the conclusion of several washings the beetles themselves were inspected and found still to have pollen on their bodies.

Table 1 gives the percentage germination of seed obtained from the self-sterile plants pollinated only by the designated insects in the first series of field experiments. Less than 1% germination was obtained from the plants preserved as checks. These results compare favorable with those obtained from previous selfing of the same plants with cloth and paper bags and demonstrate that the method of isolation employed for these tests was effective.

TABLE 1.—*Percentage germination of seed from plants pollinated by various insects collected from guayule fields, four replications.*

Insect or treatment	Percentage germination
No insects (checks)	0.425
Pollen-free ladybird beetles (100)	0.615
Ladybird beetles with pollen (100)	10.80
Lygus bugs (50)	3.40
Cucumber beetles (50)	3.10
Flies	0.72
Open-pollinated	27.10

A comparable low percentage germination was obtained when the ladybird beetles free from guayule pollen were introduced into the cages. This shows that the insects alone have no influence on pollination or germination of seed. A significant increase in seed germination was obtained from the plants with which ladybird beetles from the field were associated. The average germination was 10.8% compared with 0.425% for the checks. Smaller but significant increases were obtained through the agency of lygus bugs and cucumber beetles. It will be remembered that only 50 lygus bugs and cucumber beetles were introduced into each cage compared with 100 ladybird beetles. No significant difference was produced by the flies. An average of 27.1% of the open-pollinated seeds germinated. The data show that ladybird beetles, lygus bugs, and cucumber beetles are effective pollen carriers, but flies are not effective under the conditions of these experiments.

Data obtained from germination and classification of seedlings from controlled crosses in which insects were used as pollen carriers are summarized in Table 2. The percentage germination of seed is low but significantly higher than that for the checks (Table 1). The color classification shows that the pollen is actually carried, in the one case, from homozygous yellow pollen plants to homozygous yellow seed plants, thus producing yellow seedlings. Insects transferred from plants homozygous for green, carried pollen which was responsible for the high percentage of green seedlings. The few yellow seedlings likely are the selfs which might be expected even from such highly self-sterile yellow parents. These results show that pollen is carried by

insects from one plant to another. On the basis of these data, the amount of pollen carried by 100 ladybird beetles seems small. It must be remembered, however, that the insects were free from guayule pollen when collected and were allowed to remain only 48 hours with the pollen parent. About 500 insects were present on the same plant at the same time. Even though the plant was producing an abundance of pollen, the amount available to each insect may have been limited. Insects of the same species collected in the field obviously were better supplied. They carried enough pollen to provide for 10.8% seed germination compared with 2.12% and 1.85% for the controlled crosses. Other crosses involving these same plants made under field conditions by transferring pollen from one plant to another with a brush have been much more successful, yielding in the neighborhood of 35% germination. Plants allowed to be pollinated in the natural way produced seed showing an average germination of 27.1% (Table 1). Many factors are involved in controlled insect pollination in the field. Principal among these factors are methods of isolating plants with provision for the requirements of plants and insects; numbers, kinds, and behavior of insects; time factors concerned with the receptive stage of the flowers and viability of pollen; and source of pollen. Sterility factors known to exist in the plants cause added uncertainty in all types of crossing. Until better methods are developed, insect pollination does not seem practical for experimental crosses under field conditions.

TABLE 2.—*Percentage germination and classification of seedlings from controlled crosses, four replications.*

Insect and treatment	Germination, %	No. of yellow seedlings	No. of green seedlings
Pollen-free ladybird beetles........	0.70	6.75	0.25
Ladybird beetles from yellow plant	2.12	20.50	0.70
Ladybird beetles from green plant	1.85	1.70	16.80

GREENHOUSE STUDY

Table 3 expresses the data obtained from the greenhouse experiments. The seed from the two plants making up each pair was lumped together. Since the plants used in these insect experiments were not subjected to routine spraying, considerable numbers of insects and red spiders common to the greenhouse accumulated on the plants. This probably accounts for the average germination of 5.5% from the A plants with only their natural population. The plants (B) associated with the ladybird beetles and one species of fruit flies, (*D. melanogaster*, (C) showed a percentage germination of 26.7 and 28.8, respectively. The D plants associated with the other species of fruit flies, *D. hydei*, germinated less readily. This was anticipated on the basis of observations made while the insects were in the cages. The *D. melanogaster* were observed to move from one blossom to another more freely and seemed to adapt themselves more favorably to the conditions in the greenhouse cages than did the *D. hydei*. A com-

paratively small amount of seed was obtained from the E plants associated with the cucumber beetles. These insects were observed to injure the plants severely and undoubtedly interferred with seed production enough to off-set any value they might have as pollen carriers. The lowest percentage germination was recorded for the F plants associated with the thrips. Those insects are abundant on guayule in the fields. The thrips were likely introduced in large enough numbers to devour much of the pollen produced by the two plants and thus limit cross pollination. Appropriate tests demonstrated the fact that no foreign pollen was penetrating the cages used in these experiments in the greenhouse.

TABLE 3.—*Percentage germination of seeds following designated treatments of plants in small greenhouse cages.*

Plant pair	Treatment	Total No. of seeds	Percentage germination
A	No insects introduced	880	5.5
B	25 ladybird beetles, *H. convergens*	785	26.7
C	50 fruit flies, *D. melanogaster*	735	28.8
D	50 fruit flies, *D. hydei*	775	6.7
E	25 cucumber beetles, *D. sorro*	230	7.0
F	25 thrips, *T. tobaci*	610	2.8

Results of the second series of greenhouse experiments for which the larger cages were used are summarized in Table 4. There is no significant difference between the percentage germination from the checks and the plants with which the insects were associated. The plants brushed produced a high percentage germination. These results were anticipated because the insects did not circulate back and forth from one plant to the other as in previous experiments but collected in groups in the corners of the cages. Evidently the conditions of the experiment were not as well suited to the activity of the insects as those involving the smaller cages. It is very likely that the efforts made to remove the usual greenhouse population from the plants and thus provide better control for the experiments were responsible for the results. Sprays containing such ingredients as DDT known to have a residual effect were avoided. The removal of the insect population removed the main food supply for the beetles and thus interferred with their activity. The results indicate that many factors are involved in problems concerning insect pollination and that the insects tested are not dependable agents of pollen transfer under controlled conditions.

TABLE 4.—*Percentage germination of seeds following designated treatments of plants in large greenhouse cages, two replications.*

Treatment	Total No. of seed	Germination, %
Selfed (check)	1,784	0.61
50 beetles	1,406	0.64
Brushed	1,790	33.24

SUMMARY AND CONCLUSIONS

Large numbers of insects were collected in the guayule fields and examined microscopically and all were found to carry guayule pollen. Ladybird beetles and lygus bugs were observed to carry numerous pollen grains on their bodies. Flies were found to carry smaller but appreciable quantities. When stained with cytoplasmic stain and subjected to microscopic examination, insect-borne pollen appeared to be normal. Experiments demonstrated the fact that insects are capable of carrying pollen from one plant to another and the pollen thus transported is effective in fertilization.

One series of field experiments was conducted by placing cloth cages around self-sterile plants and introducing insects collected in the guayule fields. The percentage germination of seed showed lady-birds beetles, lygus bugs, and cucumber beetles to be carriers of pollen from one plant to another. Flies produced no significant effect under the conditions of these experiments. Controlled field crosses were made by transferring insects from one self-sterile plant to another genetically and phenotypically different self-sterile plant. The percentage germination of seed and classification of progeny demonstrated the fact that insects carry pollen which is effective in fertilization. Controlled pollination by insects in experimental field crosses does not seem practical.

Five different species of insects were introduced into small cages surrounding pairs of self-sterile plants in the greenhouse. Ladybird beetles and one species of fruit fly were found to be responsible for an increased germination of seed. The other three insects produced no significant effect. Results of further greenhouse experiments in which larger cages were used showed no significant effect from ladybird beetles. Many factors must be considered in insect pollination studies. It is doubtful that insects could be of practical importance as agents of controlled pollination in the greenhouse.

The results of both field and greenhouse experiments indicate that insects are effective carriers of guayule pollen from one plant to another in nature.

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Effect of Plant Spacing, Fall Irrigation, and Fertilization on Rubber Production During the Winter in 1-Year-Old Guayule[1]

D. C. Tingey and Wilson Foote[2]

AFTER the vegetative growth in guayule is retarded in the fall of the year as a result of lowering temperatures and possibly other factors, the shrub continues to accumulate rubber.[3] During the cold season from late November to February or March, rubber accumulation in guayule at Salinas, Calif., is usually as great or greater than for any comparable period of the year. During at least part of this interval, rubber may accumulate more rapidly than at any other season.[4] The data herein reported were obtained from an experiment to determine the effect of plant spacing, early and late fall fertilization with and without irrigation, and the interrelation of these factors on rubber production in guayule during the winter.

METHODS AND MATERIALS

Nursery seedlings were transplanted into the field during the middle of December in 1942. Except for the differential spacings, the plants all received uniform treatment up to July 30, 1943. On July 16, the plots all received a uniform irrigation.

Treatments consisted of fertilizer versus no fertilizer on July 30 and November 10 and irrigated versus nonirrigated on September 7. Since the fertilizer applied as late as November 10 showed no significant effect on pounds of rubber or tons of shrub per acre or percentage rubber during the winter, these treatments were averaged with those made prior to this date. The four treatments, namely, fertilizer versus no fertilizer on July 30 and irrigated versus nonirrigated on September 7 were repeated on three plant spacings, namely, 28 × 10 inches, 28 × 20 inches, and 28 × 40 inches. There were three replications of each plant spacing and superimposed on each replication of each spacing were four replications of each fertilizer and irrigation treatment, thus making 12 replications of these treatments. Plots consisted of 10 rows 117 feet long. In sampling the shrub for yield and percentage rubber, each plot was divided into two equal parts and a sample was taken from each part. The sample consisted of the eight inside rows, 6.5 feet long. Only plants surrounded by neighbors on four sides were used in the sample. The average field stand was about 82%.

The shrub was sampled on November 20, 1943, and March 1, 1944, which was about 11 and 14 months, respectively, from the time of transplanting. November 20 was about 4 months from the time of applying the first differential fertilizer treatments and 2½ months from the differential fall irrigation treatments and

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[1]Contribution from Special Guayule Research Project, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Salinas, Calif. Received for publication November 19, 1946.

[2]Formerly Senior Agronomist and Assistant Agronomist, respectively.

[3]The effect of temperatures and possibly other factors at this season of the year is associated with the growth conditions of the guayule plant. In the fall the vegetative growth is distinctly retarded with lowering temperature (50° F or below) and in the spring, with similar temperatures the plant resumes vegetative and reproductive growth.

[4]Tingey, D. C. The effect of frequency of irrigation on rubber production in 2- and 3-year-old guayule. Unpublished report, on file in the office of the Special Guayule Research Project. 1944.

the corresponding intervals to March 1 were approximately 7 and 5½ months, respectively. The interval between November 20 and March 1 is referred to as the winter period.

The application of fertilizer made July 30 consisted of 260 pounds of ammonium phosphate (11–48–0) per acre and the one on November 10 of 32 pounds of nitrogen and 64 pounds of phosphoric acid per acre. The nitrogen and phosphoric acid were applied in a mixture of ammonium phosphate and ammonium sulphate. The fertilizer in each case was placed in bands on each side of the row approximately 8 inches from the plants and 4 inches deep.

The irrigation treatment on September 7 consisted of wetting the soil to a depth of 6 feet or deeper.

Climatic conditions at Salinas, Calif., where the experiment was conducted, is characteristic of the coastal area. The winters are mild and the summers cool. The precipitation (about 14 inches annually) occurs almost entirely between November and May. Table 1 lists the temperature and rainfall data from July 1943 to April 1944, the interval covered by the principal part of this experiment.

TABLE 1.—*The mean monthly maximum and minimum temperatures and rainfall for 1943–44 and the deviations from the average for 1925–44.*

Month	Mean temperatures, °F		Deviation from average 1925–44, °F		Rainfall, inches	Deviation from average, 1925–44, inches
	Max.	Min.	Max.	Min.		
			1943			
July	75°	54°	0	2	0	−0.29
Aug.	76°	53°	1	0	0	−0.27
Sept.	80°	54°	4	4	0	−0.11
Oct.	76°	47°	0	0	0.31	−0.18
Nov.	73°	44°	1	3	0.24	−0.90
Dec.	62°	41°	−3	2	1.75	−0.93
			1944			
Jan.	63°	40°	0	1	2.30	−0.90
Feb.	62°	40°	−2	0	5.17	2.23
Mar.	70°	41°	1	−2	1.20	−0.88
Apr.	66°	44°	−4	−1	1.79	0.02

During 1943, the year the differential fall irrigation and fertilization treatments were made, no rainfall occurred during July, August, and September and very little in October and November. The soil moisture, except for the immediate surface, would not be affected by the rainfall before December. By March the moisture from the natural precipitation had penetrated to a depth of 6 feet or more in in nonirrigated plots. Rainfall from July 1943 to March 1944 was somewhat lower for each month except February than for the 1925–44 average. Yield data on pounds of rubber and tons of shrub per acre and percentage rubber were subjected to a statistical analysis by the variance method.[5]

The soil on which the experiment occurred, ranged from Hanford sandy loam to Hanford coarse gravelly loam. Field moisture capacity varied between 7 and 10% and the wilting percentage between 2 and 3.5 to a depth of 6 feet.

Soil samples were taken from the plots on August 20 and November 6. On August 20, before any differential fall irrigation, the moisture in the first foot averaged about 6%. On November 6, 2 months after the differential fall irrigation treatment, the soil moisture in the irrigated plots averaged 4.2% in the first foot and increased to 10% in the 5 to 6 foot depth on the plots with plants

[5]FISHER, R. A. Statistical Methods for Research Workers, Edinburgh Oliver & Boyd. 1935.

spaced 28×10 inches. In the plots not fall irrigated and at the same spacing, the soil moisture in the first foot averaged about 3% and was only slightly above this percentage to a depth of 5 feet. In the 5 to 6-foot depth, the soil moisture averaged 6.9%. On plots with a plant spacing of 28×40 inches not fall irrigated, the soil moisture averaged about 4% in the first foot, increased to 9.6% in the 5 to 6 foot depth, and was only slightly lower than the fall irrigated at the same spacing.

Hence, the plants irrigated on September 7 were in soil relatively high in available moisture, and those not irrigated, especially the closer spacings, were in soil relatively low in available moisture during the fall and early winter.

EXPERIMENTAL RESULTS

Table 2 lists the pounds of rubber and tons of shrub per acre and the percentage rubber in the shrub for the two dates of harvest, and the increase and percentage increase during the winter.

POUNDS OF RUBBER PER ACRE

On November 20 and March 1, 11 and 14 months respectively from date of transplanting, the yield of rubber was progressively higher for the closer spacings.

On November 20, 4 months after the differential fertilization treatment and 2½ months after the differential irrigation treatment, irrigated unfertilized shrub was significantly lower in yield of rubber than any of the other treatments, and the differences were progressively greater for the closer spacings. On March 1, 7 and 5½ months from the time of the differential fertilization and irrigation treatment, respectively, the fall-irrigated unfertilized shrub yielded about the same amount of rubber as the non-fall-irrigated shrub either with or without fertilizer. However, the fall-irrigated and fertilized shrub on March 1 yielded significantly more rubber than any of the other treatments and the differences were progressively greater for the closer spacings. This shows an inter-relation between irrigation, fertilization, and spacing on rubber production in guayule from samples taken in both the fall and in the spring.

During the winter months (November 20 to March 1) guayule produced as an average of all the treatments 1⅓ times as much rubber as during the preceding 11 months. The increase was due largely to an increase in percentage rubber rather than in dry weight of shrub.

Rubber production during the winter was determined to a considerable extent by the amount of shrub at the beginning of the winter period.

Rubber production during the winter was progressively greater for shrub on the closer spacings. It was also significantly higher for the fall-irrigated shrub. Fall-irrigated and fertilized shrub accumulated significantly more rubber during the winter than fall-irrigated unfertilized shrub. On the 28 x 10 inch plant spacing the fall-irrigated and fertilized shrub produced nearly twice as much rubber during the winter as the non-fall irrigated shrub either with or without fertilizer, whereas on the 28 x 40 inch plant spacing fall-irrigated and fertilized shrub produced only a few pounds of rubber per acre more than the non-irrigated shrub. This shows a significant inter-relation between spacing, irrigation, and fertilization on the production of rubber during the winter. The highest rubber production during this time

TABLE 2.—*Pounds of rubber and tons of shrub per acre and percentage rubber on November 20, 1943, and March 1, 1944, and the increase and percentage increase during this interval.**

Spacing inches	November 20 sampling (11 months in the field)				March 1 sampling (14 months in the field)				Increase or decrease from Nov. 20 to Mar. 1				Percentage increase or decrease from Nov. 20 to Mar. 1			
	Not fall irrigated		Fall irrigated		Not fall irrigated		Fall irrigated		Not fall irrigated		Fall irrigated		Not fall irrigated		Fall irrigated	
	No fertilizer	Fertilized	No fertilizer	Fertilized	No fertilizer	Fertilized	No fertilizer	Fertilized	No fertilizer	Fertilized	No fertilizer	Fertilized	No fertilizer	Fertilized	No fertilizer	Fertilized
Pounds of Rubber Per Acre																
28×10	104	96	76	93	173	161	172	213	69	65	96	120	66	68	126	129
28×20	56	60	50	57	113	128	125	140	57	68	75	83	102	113	150	146
28×40	28	28	28	30	71	76	75	84	43	48	47	54	154	171	168	180
Average	63	61	51	60	119	122	124	146	56	60	73	86	107	117	148	152
Tons of Shrub Per Acre (Dry Weight)																
28×10	1.11	0.93	1.10	1.29	1.05	0.98	1.27	1.47	−0.05	0.05	0.17	0.18	−5	5	15	14
28×20	0.68	0.71	0.78	0.88	0.77	0.85	0.94	1.00	0.09	0.14	0.16	0.12	13	20	21	14
28×40	0.40	0.44	0.45	0.53	0.50	0.52	0.56	0.61	0.10	0.08	0.11	0.08	25	18	24	15
Average	0.73	0.69	0.78	0.90	0.77	0.78	0.92	1.03	0.05	0.09	0.15	0.13	11	14	20	14
Percentage Rubber																
28×10	4.9	5.2	3.4	3.6	8.5	8.3	6.9	7.4	3.6	3.1	3.5	3.8	73	60	103	106
28×20	4.2	4.3	3.2	3.3	7.5	7.8	6.7	7.1	3.3	3.5	3.5	3.8	79	81	109	115
28×40	3.5	3.2	3.1	2.9	7.2	7.4	6.9	7.0	3.7	4.2	3.8	4.1	106	131	123	141
Average	4.2	4.2	3.2	3.3	7.7	7.8	6.8	7.2	3.5	3.6	3.6	3.9	86	91	112	121

*Transplanted December 11–16, 1942.

was in shrub at the closest spacing, fall irrigated and fertilized. Shrubs at the wider spacings were unable to use, to advantage, additional moisture and fertility.

While shrub on the closer spacings showed the greater rubber production in pounds, shrub on the wider spacings showed the highest percentage increase during the winter, whereas fall-irrigated shrub compared with non-irrigated showed both a higher production in pounds of rubber as well as in percentage increase during the winter.

TONS OF SHRUB PER ACRE

On November 20 and March 1, the yield of shrub was progressively higher for the closer spacings. Fall-irrigated and fertilized shrub yielded significantly higher than shrub with any of the other treatments.

On March 1, fall-irrigated and fertilized shrub yielded significantly higher in dry weight than the unfertilized and the latter yielded significantly higher than the non-fall-irrigated either fertilized or unfertilized.

The increase in dry weight of shrub during the winter was not significantly different for spacings or fertilized versus unfertilized, but was significantly higher for the fall-irrigated shrub. There was a significant interaction between spacing × fall irrigation treatment. Shrub at the closer spacing without fall irrigation showed no increase in dry weight during the winter.

PERCENTAGE RUBBER

On November 20 the percentage rubber was consistently higher in the shrub on the closer spacings and with one exception this was true also on March 1. Fall irrigated shrub was consistently lower in percentage rubber on both dates of harvest than nonirrigated shrub. On November 20 there was no significant difference in percentage rubber on fertilized and unfertilized shrub, however, on March 1 the fall-irrigated, fertilized shrub was significantly higher in percentage rubber than the fall-irrigated, unfertilized shrub.

Increase in percentage rubber in the shrub during the winter was slightly greater for the shrub on the widest spacing as compared with the other spacings. Fall-irrigated and fertilized shrub showed a slightly higher increase in percentage rubber during the winter than shrub with any of the other fertilizer or irrigation treatments.

The percentage increase in rubber in the shrub from November 20 to March 1 was progressively higher for the wider spacings and it was higher for fall irrigation. Fall-irrigated fertilized shrub showed a higher percentage increase in rubber for each spacing during the winter than the fall irrigated, unfertilized shrub.

SUMMARY

During the 3 winter months (November 20 to March 1), guayule 1 year of age produced, as an average of all the treatments, one and one third times as much rubber, one seventh as much dry weight of

shrub, and an equal percentage of rubber as during the preceding 11 months. The increase in pounds of rubber during the winter in the different treatments varied from 66 to 180%, in shrub tonnage they varied from a 5% loss to a 25% increase, and in amount of rubber they varied from 60 to 141% increase. Rubber production during the winter was inter-related with spacing, irrigation, and fertilization.

The maximum rubber production during the winter was obtained with the closest spacing, fall irrigation, and fertilization.

A Comparison of Methods Used in Evaluating the Results of Pasture Research[1]

H. L. AHLGREN[2]

THE importance of pastures in the agricultural economy of the United States is clearly apparent on the basis of available statistical data. These data indicate that pastures occupy 55% of the total land area and they provide approximately 50% of the nutrient requirements of all classes of livestock (114).[3] The production of this extensive acreage is harvested directly by livestock and processed into beef, mutton, milk, wool, and other livestock products.

The outstanding characteristic of the area used for pasturage in the United States is undoubtedly its extreme heterogeneity. Variations in soil, seasonal and annual rainfall, temperature, altitude, latitude, and day length have regionalized or even localized many of the problems in connection with pasture improvement. Such variations account for the comparatively large numbers of forages which are utilized for grazing within regions and in addition they provide a ready explanation for the marked changes in the species content of the sward from region to region (94).

The productivity of pastures in most sections of the United States is relatively low. The number of acres of pasture on the average farm is determined largely by topography, climate, soil type, and type of farming, and is not based on the value of pasture in relation to other farm crops. In practice there is a marked tendency on the part of farmers to relegate the pastures to the poorest parts of their farms. The low production of pastures in the United States is due primarily to the single or combined effects of lack of fertility, low annual rainfall, seasonal drought, improper grazing management, shading of forage in wooded areas, and injury from certain insects and diseases.

At present there is among research investigators and others a growing interest and awareness of the value and importance of good pasture. Its value as a source of highly nutritious, succulent forage and its importance in maintaining the health of livestock is well known. While data are admittedly insufficient and fragmentary, there is some indication from studies by White (109), McConkey (65), and others that under some conditions yields of total digestible nutrients produced from adequately fertilized and well-managed pastures may compare favorably with those of cultivated crops. Likewise, Misner (69), Woodward and Shepherd (112), Arny (7), Pelletier (82), and others have presented evidence showing that pastures provide the cheapest and most economical source of feed for most classes of livestock. In addition, studies initiated by Miller (66) in Missouri and repeated subsequently by workers in many other areas have clearly

[1]Contribution No. 221 from the Department of Agronomy, University of Wisconsin, Madison, Wis. Presented at the annual meeting of the American Society of Agronomy, Omaha, Neb., Nov. 20, 1946. Published by permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication December 9, 1946.

[2]Professor of Agronomy.

[3]Figures in parenthesis refer to "Literature Cited", p. 254.

demonstrated the value and importance of hay and pasture forages in soil conservation and improvement.

Substantial progress has been made in the field of pasture research during the past 25 to 30 years. Unfortunately, however, acceptance of the findings of research by the farmers of the nation has been disappointingly slow. The reason for the failure of farmers to make extensive use of improved and tested pasture practices is not clear, but it may be due, in part at least, to (a) the common misconception that pastures are able "to shift for themselves" or (b) the failure to interpolate results in terms which are easily understood by farmers. In general, farmers have but little conception of the importance and value of results measured in and presented to them as increased yields of dry matter, superior quality based on routine chemical analyses, more cow pasture days, greater palatability, etc. Studies in which results are measured according to these procedures are necessary and important in pasture investigations, but to the realistic and conservative farmer they are not conclusive. It appears that progress in acceptance of the findings of research in the field of pasture improvement will continue to be slow until results based on gains in live weight or increases in milk, wool, or other products per dollar invested for seed, fertilizer, or for other practices leading to increased productivity can be made available to extension agronomists and farmers.

It is the purpose of this paper to review methods and techniques which have been or are now being used in measuring pasture improvement practices and to consider some of their advantages and limitations in the light of information which is available.

EVALUATION DIFFICULT

Pasturage is harvested directly by livestock, whereas forage used for hay or ensilage, small grains, corn, and other feed crops are harvested mechanically by machines. In pasture research both livestock and mechanical equipment are used in measuring results even though it is recognized that animals graze preferentially and affect the sward in a manner which cannot be duplicated by mechanical harvesting. Stapledon and Jones (99) have shown that sheep graze some species before others and that the leaves of plants are generally preferred to the stems. While it would be highly desirable to base all results on studies which include the use of livestock, it is often necessary to rely on less accurate techniques to reduce costs and make the most effective use of available experimental areas. To be most effective any method or technique used in measuring results must (a) be relatively inexpensive, (b) be reliable and reasonably unbiased, and (c) provide results within a reasonable period. Methods of measurement must take into consideration the many variables occasioned by differences in species, relative palatability, stage of growth, management, fertility, and climate.

MANY METHODS USED

Because of the complexity of problems associated with pasture improvement and the many variations in vegetative cover resulting

from differences in soil, climate, topography, and elevation within and between regions, it is not surprising to find that a comparatively large number of methods have been developed for evaluating improvement practices. Schuster (93) has reported that 13 methods of measurement have been used in determining the productivity of pastures in the eastern portion of the United States.[4] The methods listed include profit, hay weights, clippings, cattle weights, sheep weights, photographs, surveys, carrying capacity, milk flow, plant population, chemical analysis, palatability, and duration of grasses. Vinall (107) has proposed the "unit day of grazing". With the aid of feeding standards prepared by Haecker (41), Morrison (71), Forbes, *et al.* (35), and Knott, *et al.* (58) have used the total digestible nutrient method for determining the productivity of pastures. A similar procedure has been applied by Sprague (96), Ahlgren, *et al.* (2), Nevens (74), Robinson, *et al.* (87), and Schaller, *et al.* (91) in measuring the productivity of pastures in New Jersey, Wisconsin, Illinois, and West Virginia. Knott, *et al.* (58) have proposed the standard cow-day as a means of expressing the carrying capacity of pastures. Albrecht and Smith (3), McLean, *et al.* (64), Smith and Albrecht (95), and Crampton, *et al.* (23, 25) have suggested that small animals such as rabbits may be effectively utilized in assaying the feeding efficiency and nutritive value of forages.

It is apparent from the foregoing that indirect methods and techniques are used for the most part in evaluating pasture improvement practices. More exact information on the actual feeding value of pasture forages than is provided by these indirect procedures would be extremely valuable in most types of pasture investigations. Unfortunately, there is very little information in the literature (1,38,84) relative to the feeding value of forages grazed at immature stages of growth.

METHODS OF MEASURING RESULTS

PROFIT

Schuster (93) has stated that in measuring results on the basis of profit it is necessary to consider increases in animal weight, increases in milk flow, increase over investment, and interest on investment. Profit as such, however, is not a technique or procedure for evaluating pasture improvement practices. Rather it is a means of interpolating data, and expressing and presenting results in a manner which is easily understood by farmers. It appears that results of studies which lend themselves to such interpolation will be more readily accepted by farmers than will equally precise results presented in a less tangible manner. Results of studies involving the use of livestock are more readily presented on the basis of profit than those based on other methods of measurement. Unfortunately, however, investigators are usually limited to a few carefully selected variables because of the relatively high expense of most studies which includes the use of livestock.

[4]An excellent review of problems and methods used in connection with range research is presented in "Proceedings of Range Research Seminar". These proceedings were published by the Forest Service, U. S. Dept. of Agriculture, in 1939.

HAY WEIGHTS

Hayweights have been used in a number of instances as a means of evaluating certain pasture improvement practices. When this procedure is used it is assumed that forages will react similarly under hay and pasture conditions. Graber, *et al.* (39), Stapledon (100), Wiggans (110), and others have presented conclusive evidence to show that the yields of many forages are decreased considerably as the number of defoliations is increased. In addition, interactions with respect to dominance and survival of species grown in mixtures may differ considerably under hay conditions compared with clipping or grazing treatments which involve more frequent defoliation. Thus it seems that hay yields may not be representative of results which are likely to prevail under grazing conditions. It would appear that this method of measurement is of limited value in pasture studies and that it may be eliminated entirely with considerable justification or severely restricted to preliminary trials of an observational nature.

YIELD OF DRY MATTER FROM IMMATURE FORAGES

Clipping or mowing ungrazed plots or protected areas in pastures which are grazed to obtain yields of dry matter is probably the most common procedure used in measuring the results of pasture research. The method is easy to employ, rapid, and relatively inexpensive. It is admirably suited to trials which include a large number of variables and for small plot types of studies.

Many differences in sampling technique have been reported when this procedure of measurement is employed. Various investigators harvest forage samples with hand sickles, grass shears, lawn mowers with grass catchers, field mowers, and by hand plucking. Protected sampling areas in grazed pastures vary in size from a few square feet to one or more square rods. They are sometimes permanently located in grazed pastures or they are relocated annually, semiannually, or following the completion of each grazing period. Yields of caged or protected areas are determined directly or by various "difference methods". Frequency of harvesting varies from weekly or monthly intervals to once or twice a year, and height of cutting from 1 to 2 inches to that left by the cattle after grazing is completed.

The accuracy and value of results based on mechanical clipping, plucking, or mowing are now known. Data which appear in the literature indicate that results may be higher, lower, or about the same as those obtained from grazing animals. Gardner, *et al.* (37), Brown (16), Jones, *et al.* (54), Hodgson, *et al.* (47,48), Brandt and Ewalt (14), and Ahlgren, *et al.* (2) have reported higher yields from clipping or mowing than from grazing. Linehan and Lowe (62) found that total digestible nutrients calculated from clippings were approximately equal to those determined by livestock methods. In other studies, Brandt and Ewalt (14) have presented results which are in essential agreement with those of Linehan and Lowe. Robinson, *et al.* (87) have shown that yields from clipped permanent plots gradually decreased in relation to the yields obtained in grazing, but there were high correlations between the yields from clipping and those from

grazing from year to year. Brown (16) concluded that yields from continuously clipped permanently caged areas were lower than those of cages moved annually. In other studies, Brown and Munsell (17) observed that permanently caged areas had less grass, many more weeds, much more bare ground, and consistently smaller yields, including the weeds, than nearby areas caged for only one year. On the basis of these results they have questioned the applicability of fixed cages as a substitute for grazing in measuring the production of pastures. Close correlations between results from mowed plots and those obtained by grazing are found in the results of Brown (16), Hodgson, *et al.* (47, 49), Noll, *et al.* (75), Robinson, *et al.* (87), Nevens (74), Gardner, *et al.* (37), Ahlgren, *et al.* (2), Brandt and Ewalt (14), and Linehan and Lowe (62). On the other hand, Brown and Munsell (17), Garrigus and Rusk (38), Schaller (92), Brown (18), Fuelleman (36), Jones (52,53), and Rhoad (85) have reported poor or low correlations in certain instances between yields from mowed and grazed plots. Woodward, *et al.* (113) have shown that annual yields from caged areas were decreased with increases in frequency of harvesting. Ritchey and Henley (86) found that more accurate yields were obtained by plucking than by clipping. Klingman, *et al.* (57) studied the accuracy of various sampling procedures and concluded that (a) for estimating consumption by the difference method it is more efficient to choose one unit at random and the second similar to the first than to choose both at random and (b) it is more efficient to place cages singly than in groups. In order to simulate grazing more closely Hudson (50) has devised a procedure of sampling involving alternate grazing and mowing of experimental areas.

On the basis of data given in the literature, there is evidence for a substantial difference of opinion with respect to the validity of results based on yields from mowed plots compared with those of grazed areas. However, most investigators have reported that results based on clipping trials which simulate grazing approximate those obtained in grazing during the first few years. There is some indication, however, that significant changes may occur in the botanical composition of grazed and mowed areas (45,99,102) and that clipped areas deteriorate progressively in quality and productivity as time goes on (17,87). In view of these results it appears highly desirable to avoid the use of permanent sampling areas in grazing trials and to relocate cages or other sampling devices at reasonably frequent intervals. It is clear that additional information is needed relative to the value and accuracy of results based on clipping or mowing compared with those obtained in grazing trials. Until such information is more generally available, results of clipping or mowing trials can be interpreted only as being indicative of those likely to prevail when livestock are used.

PRODUCTION OF MILK

Evaluations based on milk production provide results which are easily translated to cash values. The economic significance of such results are more apparent to farmers than those based on agronomic or biochemical procedures. Because of the relatively high costs in-

volved, trials of this nature are usually limited to a few carefully selected variables. Recommended procedures (84) for the selection, allotment, and weighing of animals and for supplemental feeding should be followed to reduce errors of sampling. Knott, *et al.* (58) have pointed out that many variable factors may obscure results when measurements are based on milk production. They have stated that "when quantity of milk per acre is used as the measure of results, it is necessary, where comparisons are made, to have maintenance requirements and live weight gains the same. The amount of supplemental feed used is also a factor that may lead to false interpretation of results".

CATTLE AND SHEEP WEIGHTS

The use of dairy heifers, beef cattle, and sheep for evaluating pasture practices has the marked advantage of measuring results under actual grazing conditions. In addition, data which are obtained are readily converted to cash values. Less difficulty is usually encountered in conducting trials involving these classes of livestock than is likely to occur in studies which include lactating dairy animals. When results are to be measured in terms of livestock weight increases, recommended procedures (84) for the selection, allotment, and weighing of animals and for supplemental feeding should be followed.

The kind of animal for which the results are to apply should be used when measurements are based on live weight increases since data obtained with one class of livestock are not readily applied to other classes of livestock. Likewise, grazing habits and tramping effects of sheep and beef cattle or dairy cattle are entirely different, and it is likely that their respective effects on the sward will differ.

Standards for computing the nutrient requirements of dairy heifers, beef cattle, and sheep are available. Thus, results based on gains in live weight can be readily converted to total digestible nutrients when such conversion is desirable.

Trials involving dairy heifers and beef cattle are often restricted by cost, lack of suitable available livestock, and other limitations to a study of relatively few variables. With sheep, however, the number of variables under investigation are frequently increased without excessive expense. Stapledon and Jones (99,102) have developed techniques applicable to sheep for evaluating pasture practices. Their procedures, which include tethering, movable pens, and small enclosures, have been effectively used in pasture trials in Great Britain and elsewhere.

PILOT PLOTS

Sheep and cattle are sometimes used to advantage as "natural lawnmowers" and to provide "grazing effects" in studies designed to obtain preliminary data on the relative value of certain treatments, species, strains, mixtures, etc. Such investigations are usually conducted on small plots. Refined methods of measurement are not required since differences are often large and the primary objective is to eliminate the poorest variables rather than to determine the best. This procedure may also serve as a means of obtaining preliminary

information on the value of new strains or varieties in early stages of development. Seed supplies of new strains or varieties are often limited and of necessity plantings are restricted to plots of small size.

Small plot investigations involving the use of livestock will likely be most satisfactory when differences in palatability between treatments, mixtures, species, or strains are relatively small. When differences in palatability are great, evaluation is difficult because of uneven grazing. Likewise, when fertility variables are included in such trials, effects are eventually "evened out" by the voidings of the livestock.

TOTAL DIGESTIBLE NUTRIENTS

Results of grazing studies involving the use of nonlactating cattle cannot be applied directly to dairy cows. Requirements for maintenance, milk production, gain or loss in live weight, and the amount of supplementary feed provided must all be considered when producing dairy cows are used in grazing trials. Knott, *et al.* (58) have reported that calculations of results in terms of total digestible nutrients is the only procedure which permits consideration of these variables. They have suggested a procedure for determining the total digestible nutrients obtained by dairy cattle in grazing. According to their procedure, total digestible nutrients provided by pastures are obtained by adding the requirements for milk production, maintenance, and live weight increases and subtracting from the total the nutrients provided in supplementary feeds. The difference represents the total digestible nutrients provided by the pasture. If yields of forage are carefully taken, the digestibility of the forage can be calculated with reasonable accuracy.

Recommended procedures for determining the yields of pastures by this method are available in the report of the joint committee of the American Society of Agronomy, American Dairy Science Association, and the American Society for Animal Production (84). Such studies are usually restricted to consideration of a few selected variables because of high cost and other limitations. Results obtained by this method appear to have more practical and tangible meaning when expressed in terms of their replacement value of such common feeds as corn and alfalfa. Prices prevailing in any area may be applied to these common feeds and money values in terms of feed replacement can be applied to the pastures. The total digestible nutrient method is considered by many to be the best available means of evaluating pasture practices on the basis of milk-producing dairy cattle.

Garrigus and Rusk (38) have suggested a method and described a procedure for determining the daily forage consumption of individual steers in grazing trials. The method is based on the assumption that under uniform conditions and for a reasonable length of time the percentages of dry matter consumed that will be digested and defecated by a given steer will be almost constant provided the source of dry matter consumed is roughage and is uniform as to species, stage of maturity, and chemical composition. With the aid of available data, they have calculated net energy maintenance requirements of steers on pasture and net energy for maintenance provided by

alfalfa, medium red clover, Kentucky bluegrass, reed canary grass, and bromegrass. The amount of dry forage needed to furnish a daily maintenance ration of net energy for each steer was calculated from the net energy values of different forages and the requirements of net energy for maintenance.

Of considerable recent interest, is a procedure suggested by Rhoad (85) for determining the maintenance requirements of mature steers under grazing conditions. He used a fixed number of animals and varied the size of the area available for grazing so as to provide only sufficient forage for maintaining live weight. He calculated that 49.7 pounds of forage were required daily for maintenance of each 1,000 pounds of live weight.

CARRYING CAPACITY

Results of grazing trials are often expressed as "cow days", or "sheep days", or "cattle days", or "pasture days of grazing." The meaning of these terms is often confusing, but they usually imply that a mature animal has grazed a given pasture for an indicated number of days. To eliminate the confusion which often prevails when results are presented in these terms, Vinall (107) proposed the use of the "unit day of grazing".

Brown and White (15) have summarized the disadvantages of all such methods, including that proposed by Vinall, as follows: (a) No record of supplementary feed provided is supplied, (b) neither maintenance requirements nor gains and losses in weight are considered, and (c) no distinction is made in the requirements of high- and low-producing milking cows. They have suggested that yields of grazed pastures be expressed in terms of some common feeding unit rather than as grazing units. Such calculations involve the necessity of keeping records of supplementary feed provided, gains or losses in live weight, and milk production. The use of "standard cows days" proposed by Knott, *et al.* (58) seems to meet the requirements suggested as necessary by Brown and White. Standard cow days per acre are obtained by dividing the total digestible nutrient yields per acre by 16. Carrying capacity is readily calculated by dividing the number of standard cow days per acre by the number of days of grazing during the season.

The value and significance of results based solely on grazing units and without supporting data on gains or losses in weight, milk production, and supplementary feed used, appears highly questionable. Such a procedure of evaluation appears to have limited value only in preliminary observational trials and under conditions where investigators are more interested in the effect of the animal on the forage than in the contrasting effect of the forage on the animal.

PHOTOGRAPHS

Photographic records are extremely valuable if supported by experimental data. They can be used to advantage to show striking differences, but they are less effective in portraying differences which are small but nevertheless often significant. Schuster (93) has reported that accurate ratings for various grass mixtures and fertilizer

treatments under grazing conditions were not possible from photographic records. He concluded that photographs may be used as an aid in depicting and measuring changes but not as the only means of evaluation.

Photographs taken at different periods of the growing season and from year to year provide accurate and helpful records of changes which occur as a result of differences in management, fertilization, and seasonal conditions. They are valuable in describing techniques which are used in pasture investigations, and they are also helpful to extension agronomists who are responsible for effectively presenting the results of research to farmers.

SURVEYS

Surveys are often made to obtain general impressions of pasture conditions and to orient problems of major importance. They are not an accurate or reliable means of evaluation and should serve only as a background for developing research programs designed to solve the major problems of an area or region.

BOTANICAL COMPOSITION

Systematic, periodic surveys or determinations of the botanical composition of the sward are considered essential in many types of pasture studies. Changes in botanical composition are frequently an accurate index of the effect of managerial and fertilizer treatments on the growth and survival of the species which comprise the sward. Records of changes in the botanical composition of the sward are often helpful in explaining differences in yield and changes in chemical composition of forage. To measure such changes in composition, botanical surveys are made annually or semi-annually and, insofar as possible, at the same time or times each year.

A large number of methods for determining the botanical composition of the sward have been described and discussed in American and foreign literature (4,6,12,19,20,29,30,31,32,33,40,42,43,44,46,56,59, 60,61,77,78,79,80,81,83,89,90,97,98,103,105,106). Results based on actual separations of forage from randomly selected areas are most accurate. However, this method of obtaining data is slow, tedious, and expensive and has largely been abandoned in favor of less accurate procedures which are more rapid. Many of these methods differ in principle and in ultimate objective. Some are valuable in measuring productivity while others are useful in determining ground cover, and composition or quality of the forages which comprise the sward. None of the methods can be used satisfactorily in all regions and none possesses all of the qualities which are desired. In spite of the many methods which have been developed, the need continues to exist for accurate and rapid quantitative methods which will measure, without personal bias or error, the relative frequency and productivity of the components of the sward.

While many methods are used by investigators in the United States, Great Britain, and elsewhere, Davies (30) has observed that most of them are similar to, modifications of, or combinations of the

following seven groupings: specific frequency, charting and quadrating, percentage area or percentage ground cover, point quadrat, percentage frequency, percentage productivity, and estimation methods on a 0–10 scale including percentage frequency, percentage productivity, and percentage ground cover.

CHEMICAL COMPOSITION

Chemical analysis is an indirect means of determining the nutritive value of forages. Nevertheless, this method has been widely used because it is easier to apply, requires less equipment, and is cheaper and less cumbersome than digestion trials, involving livestock. Exhaustive reviews of the literature bearing on the chemical composition of forages and the factors which are involved have been assembled and prepared by Beeson (10) and Orr (76). The data which are reviewed by these investigators show that the mineral content of forage is an important factor in determining its feeding value. Minerals are not only essential for growth of livestock, but in addition, deficiencies of minerals are often associated with decreased protein and lower yields and succulence, all of which bear directly on the nutritive value of the forage. Data based on chemical composition show that species present, soil type, fertility of the soil or fertilization, season of the year, stage of growth, climatic conditions, and competition from weeds, brush, or trees are the most important factors affecting the nutritive value of forages.

Very few studies have been conducted to determine the value of results based on chemical analysis compared with those obtained in actual feeding or digestion trials. For this reason data based on chemical analyses can be interpreted only as indicative of results which might be expected in feeding trials. However, it is abundantly clear from data which are available that chemical analysis may frequently be used to advantage to provide valuable information in pasture investigations. When used with other methods of measurement, it may help to explain differences in soil, plant, and animal relationships which are not readily detected otherwise. Problems associated with malnutrition in deficiency areas and toxicity in regions where selenium, arsenic, and molybdenum occur excessively (72) in the soil have been oriented and subsequently solved as a result of indicative data provided by chemical analysis. Likewise, chemical analyses for hydrocyanic acid, alkaloids, and similar compounds may indicate that forages are poisonous and should not be grazed by livestock. Chemical analysis has been used to measure the effect of fertilization, stage of growth, climatic conditions, season of the year, and shading on nutritive value, and the results along with those obtained by other methods of evaluation have served as a basis for designing procedures which provide for maximum efficiency and utilization of forage by livestock. Determination of the chemical composition of different species and of various portions of plants has provided valuable practical information which has been applied effectively in improved pasture practices. The importance of organic food reserves and their relation to growth and survival of perennial forage plants is well

known. Relationships which exist between organic food reserves and managerial treatments have provided a fundamental basis for the development of management procedures which assure high productivity and continued survival. These and many others are illustrative of the use and value of chemical analysis in the field of pasture research.

DIGESTION TRIALS

The ultimate value of immature forage harvested as pasturage is determined by the livestock themselves. Thus, the actual nutritive value of forages can be ascertained only as a result of carefully controlled feeding experiments. All other procedures of measurement are indirect. All are subject to the common criticism that they provide information which is only indicative of the actual results in terms of livestock and livestock products. They attempt to predict with reasonable accuracy what will happen when the forage is fed to livestock.

Unfortunately, present information on the actual value of forages harvested at immature stages of growth is extremely limited. The pasture committee of the American Dairy Science Association (84) has reviewed the results of 45 digestion trials and has suggested the following average coefficients of digestibility for mixed pastures: Crude protein, 75%; crude fiber, 79%; nitrogen-free extract, 80%, and ether extract or fat, 50%. These coefficients are applied directly to the chemical analysis of the forages to give the total digestible nutrient content. Lacking the chemical analysis, the dry matter is assumed to be 72% digestible. It would appear that such evaluations broadly applied to different forages, grown under varying soil and climatic conditions, are subject to considerable error. Results obtained by this method of measurement may provide only approximations of the actual feeding value of the forage.

Stapledon (102) has reported that all actively growing grasses have about the same feeding value when measured by grazing sheep and in this respect his results would tend to confirm the validity of the general procedure of measurement outlined by the pasture committee (84). However, Kirsch (55) and Crampton (22) in trials conducted with dairy cattle and growing rabbits, respectively, have found appreciable differences in the nutritive value of certain grasses. In studies conducted with rabbits, Crampton (21) has reported that reed canary grass was inferior to timothy in feeding value even though both forages were similar in content of total nitrogen. He attributed the difference to inferior quality of protein in the reed canary grass. In further trials with growing rabbits, Crampton, *et al.* (23,27) found that gains in live weight were not always correlated with differences in crude protein, crude fiber, or nitrogen-free extract of the feed. They have suggested that other factors must be responsible for differences in the nutritive value of certain feeds. Albrecht, *et al.* (3,95) in trials conducted with rabbits and sheep found that increased yields and changes in chemical composition of forage brought about by different soil treatments were not closely correlated with animal responses. Morris and associates (70) have found that the protein of spring grass is superior to that of autumn grass for milk production, where-

as Crampton and Forshaw (24) have shown that clippings of herbage grown during spring and fall supported normal growth of rabbits, while material grown during midsummer under less favorable climatic conditions proved of decidedly poor value. Maynard (63) has indicated that distribution of nitrogen compounds in forage crops, as determined by chemical analysis, does not provide a basis for assessing their value in protein nutrition. Bohstedt and Lathrop (13) measured the effects of varying fiber contents in grain rations of dairy cattle. When fiber varied from 4.5 to 14.1% each 1% increase in fiber content resulted in a decrease in the efficiency of the feed varying from 2.4 to 2.7%.

It is clear from these results that there is real need for information on the actual nutritive value of immature forages grown under various conditions and grazed by livestock. Such results can be obtained only in carefully conducted feeding trials designed to measure individually the many variables which prevail in comprehensive pasture investigations. It has been suggested (84) that the procedure recommended by Forbes and Grindley (34) be applied in these measurements.

BIOLOGICAL ASSAYS WITH SMALL ANIMALS

Unfortunately, it is often impractical to employ large animals in feeding trials. Crampton, *et al.* (25,26) and Albrecht, *et al.* (3,64,95) have suggested that growing rabbits may be used in assessing the biological value of forages. Crampton (25) and Crampton, *et al.* (26) have made comparisons between rabbits and steers in relative efficiency in utilization of forages and they have concluded that rabbits digest protein in certain rations more thoroughly, but crude fiber and cellulose less completely than steers. They have stated that rabbits digest pasture herbage less completely, but that there are close correlations between the two species in the cases of protein and lignin. They have suggested that the rabbit as a pilot animal has much promise and that additional work with it is justified.

Albrecht and Smith (3) found very close correlations between results obtained in feeding trials with sheep and rabbits. On the basis of their results, they have concluded that it appears possible to eliminate the larger and more expensive animals and use laboratory animals in experiments designed to determine the nutritive value of forages. Such results would be interpreted in equivalents of farm animals.

If additional investigations show close or definite correlations between results of feeding trials with rabbits and farm animals, a new and inexpensive procedure will be made available to obtain needed information on the actual feeding value of immature forages. Factors which affect the nutritive value of immature forages could thus be more easily assessed. In addition, such a procedure of measurement would provide a ready means of determining the accuracy and reliability of many of the indirect methods or techniques which of necessity are now commonly used.

RELATIVE PALATABILITY OR PREFERABILITY (104)

Relative palatability of forages has been used by some investigators (93) as a means of measuring certain improvement practices. In

general, cattle prefer some grasses or legumes to others if they are given an opportunity for selective grazing. However, when cattle are limited to less palatable species they sometimes perform about as well as those restricted to more palatable types provided both are of equal value in other respects. Even if it is assumed that high palatability is significant from the standpoint of the value of forages as pasturage, it is generally recognized that palatability is only one of the factors which affect their nutritive value. It is doubtful, therefore, if this procedure can be justified as a sole means of measuring the results of pasture research.

Studies conducted by a number of investigators (5,8,9,11,28,51,67, 68,73,76,88,101,105,108,111,115) have shown that many factors affect the palatability of forages. Among the most important of these are density of growth, taste, individual differences in animals, kind of livestock, drought resistance, species, stage of growth or succulence, mineral and vitamin A content, fertility of soil, harshness or hairiness of foliage, season of year, moisture content of soil, and whether or not species are grown in mixtures or as pure cultures. It is readily apparent, therefore, that the palatability of any forage at any given time is relative, being high or low according to the total or mass effect of all factors which affect its palatability under a given set of conditions.

Detailed observations on the relative palatability of forages grown in various mixtures, at different levels of soil fertility, or under different management treatments may, if supported by other data, be helpful in the development of mixtures, fertilization, and managerial practices which provide pasturage of relatively high palatability. When adequately supported by other data, observations on palatability are also often valuable in accounting for differences in milk production, live weight increases or decreases, and changes in the botanical composition of the sward.

DURATION OF GRASSES

Since grasses and legumes are commomly sown in mixtures for pasturage in humid areas, it is assumed that the term "grasses" is used in a broad sense to include legumes. Evaluation of pasture research on the basis of "duration of grasses" is reported (93) to have been used in some investigations prior to 1927, but it is doubtful if this procedure is applied at present. When this method of measurement is employed, it is apparently assumed that practices which fail to assure the survival of desired species are undesirable and conversely procedures which favor the survival of the forages are highly satisfactory. Results based on this method of measurement lack specificity and precision, and they are generally less valuable than those provided by other procedures. Information relating to the survival of species is clearly necessary in many types of investigations. However, such information, along with other equally valuable data, are readily obtained in one or more of the methods which have already been considered.

SUMMARY AND CONCLUSIONS

Yields and other values of most harvested feed, food, and fiber crops are readily determined by generally recognized techniques and procedures which have been developed by common experience or through the efforts of research. Unfortunately, similar procedures of measurement applicable generally to immature forages grazed by livestock are not available. Evaluation of pasture research is complicated by the need for frequent sampling under conditions where immature forages are periodically removed in grazing and by lack of information on the general relationship between the forage consumed and its effect on animal growth and production.

The nature and complexity of problems associated with pasture research and the many variations in vegetative cover resulting from differences in soil, climate, topography, and elevation within and between regions have resulted in the development of a large number of widely different methods all having as their common objective the evaluation of pasture research. Methods or techniques which have been or are being used have been reviewed and their respective advantages and limitations have been considered. The following is a summation of observations and certain conclusions which appear warranted on the basis of current known information:

1. Most methods of measurement have some value when properly applied, but some procedures are considerably more effective than others.

2. Sixteen methods for measuring the results of pasture research have been reviewed. Seven of these procedures, namely, hay weights, yields of dry matter of immature forages, photographs, surveys, botanical composition, chemical composition, and duration of grasses do not involve the use of livestock. Nine of the methods, including profit, production of milk, cattle and sheep weights, pilot plots, total digestible nutrients, carrying capacity, palatability trials, digestion trials, and biological assays with small animals, are based on results provided by livestock. Although fewer in number, methods of measurement which do not involve livestock are more commonly used than those based on livestock.

3. Carefully designed and executed trials which involve the use of livestock provide the most accurate results not only from the standpoint of the effect of the forage on the livestock but also from the equally important viewpoint of the effect of the livestock on the forage. Unfortunately, present techniques which include the use of farm animals are relatively more expensive and they require comparatively larger experimental areas than other methods of measurement. Of necessity, therefore, they must be limited to studies of a few carefully selected variables.

4. Procedures which are not based on the use of livestock probably provide less accurate results than those involving livestock. They are frequently necessary, however, in initial phases of pasture investigations where, of necessity, a large number of variables are included. The lower cost of such procedures, their greater ease of execution, and smaller requirements for experimental land areas have resulted

in their widespread use and application in measuring the results of pasture research. To be most accurate, all such procedures must simulate grazing insofar as possible and results should be arranged in groupings which include "highest" or "lowest", "best" or "poorest" for the qualities under investigation. Final evaluations of practices which fall in the "highest" or "best" groupings must be made on the basis of techniques involving the use of livestock.

5. All procedures now commonly used in measuring the results of pasture research are indirect. There is a real need for information on the actual nutritive value of immature forages fed to livestock. Such information can be obtained only in carefully controlled digestion trials. Trials of this nature would not only be valuable for their precise data, but in addition, the results would provide a basis for determining the reliability or accuracy of the indirect methods now commonly used.

6. There is need for additional studies designed to determine relationships between chemical composition, biological assays with small animals, and large farm animals. If satisfactory correlations are found, small animals can be used more extensively in measuring the results of pasture research than is possible when larger animals are involved.

7. There is need for studies designed to ascertain the value and importance of the trampling and grazing effects of livestock. Such effects cannot be duplicated in "lawn mower" types of investigation.

8. Excepting in preliminary or observational types of studies, the animals selected for use should be those for which the results are to apply.

9. There is an urgent and ever-growing need for additional information which would permit a more accurate evaluation of pastures in relation to each other and to other crops grown as feed for livestock.

10. Research workers have generally failed to interpolate results in terms which are readily understood and enthusiastically accepted by farmers. Results which are provided in trials involving livestock are more readily expressed as cash values than those obtained by other procedures.

11. It is clearly apparent from the literature that pasture research would benefit considerably and results would have greater significance if there were closer working relationships between investigators in the fields of agronomy, soils, and animal nutrition than has prevailed in most instances in the past.

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Note

POSSIBLE PRACTICAL METHOD FOR PRODUCING HYBRID SEED OF SELF-POLLINATED CROPS THROUGH THE USE OF MALE-STERILITY

THE following plan is suggested as a means for producing hybrid seed on a commercial scale in barley, wheat, and other normally self-pollinated farm crops.

The effect of environment on the phenotypic expression of genetic characters is well known. Thus, it would seem possible that the expression of some factors for male-sterility would be suppressed in certain soils or climates. The observations of the writer and others on the variation in certain male-sterile stocks from greenhouse to field cultures, from one location to another, and from season to season lend support to this expectation. As a result it would be possible to produce fertile lines of varieties that were homozygous for genes for male-sterility. Seeds from these lines when grown in other localities would produce only male-sterile plants that could be sown in rows adjacent to another, pollen-producing variety. Under these conditions —even in self-pollinated species such as barley and common wheat— there is a considerable percentage of seed set on male-sterile plants (25% set or better in many cases), which would be hybrid seed and could be used in the production of the commercial crop by farmers.

Using barley as an example, the program would be to obtain male-sterile stocks in, say, Wisconsin. The use of irradiation would probably be desirable to increase the frequency of male-sterile mutants. These would be tested for male-sterility in several places. If a number of mutants were found and so tested, it would be a reasonable expectation that among them would be one that was male-sterile in one location and fertile in another. This would be the desired stock and the gene could probably be transferred by backcrossing into any variety for combining with any other variety in the production of hybrid seed adapted to a given area.

It is obvious that such a plan, if successful, could result in the production of hybrid seed on an economically profitable basis. The chief doubt in the writer's mind regarding the feasibility of the plan is not whether male-steriles with the desired behavior can be found, but whether the low percentage of natural crossing (particularly with a crop such as barley that has an especially low frequency of natural crossing) and the increased cost of production would make the hybrid seed too expensive to be profitable. However, hybrid seed could provide special advantages and be worth a considerable premium by developing a better root system that would reduce heaving and increase drought resistance, and by producing a more vigorous growth that would be better able to compete with weeds.

Hybrids between related lines of wheat or barley that are segregating male-sterile plants could be obtained on a considerable scale for testing the results of Jones and Singleton with maize. These investigators have found that hybrids between certain closely related inbred strains of maize show marked heterosis. If their results were verified

in self-pollinated crops, hybrid populations between male-sterile plants and normal plants of the parent variety that had been separated for several generations might have the desired hybrid vigor.—

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Book Reviews

THE SOIL AND HEALTH: A STUDY OF ORGANIC AGRICULTURE

By Sir Albert Howard. New York: The Devin-Adair Company. XII+320 pages, illus. 1947. $4.

IN THIS book Howard reiterates and expands his views on agriculture set forth in *An Agricultural Testament.* It is much the same blend of personal experience and theory as a back fence conversation and with the same chatty disorganization. The language is stronger, the mood of the author more severe, but the reasoning less rigorous than in the previous book. The rather biting critique of the "scientific" approach to agriculture, loses much of its effectiveness against the lack of rigor and the bias in the author's development of his principal thesis. His outline of the spread of the Indore process into general agricultural practice is good.

In general the thesis is the same as the Testament: All material taken from the soil must ultimately be returned to the soil. The use of "poisonous artificials" to make up for our failure to obey this "Law of Return" leads to disease and ultimately to the complete destruction of agriculture. The author amplifies his theory that mycorrhizal association is a dominant factor in plant nutrition. Also, the hypothesis that disease is a manifestation of malnutrition is reiterated. The corollary that insect, fungi, or virus associated with the disease are indicators of the disease rather than the causative agents is still unconvincing. The inclusion of McDonagh's fanciful theory of climate-actuated pulsations in relation to the nature of disease seriously detracts from rather than contributes to the author's hypothesis.

That the return of wastes to the land, the maintenance of soil organic matter, and the improvement of nutritive levels are major agricultural problems is not to be denied. That the relation of soil to health is real and needs careful, unbiased evaluation and comprehensive study is generally accepted. Howard, with his frequent cry of vested interest, his unwarranted accusation of cowardice to face trial with the compost hypothesis, is neither unbiased in his evaluation nor comprehensive in his study.—C. STAFFORD BRANDT.

COLONIAL AGRICULTURAL PRODUCTION

By Sir Alan Pim. Neu York City: Oxford Universitv Press. IX+190 pages. 1947. $3.

THE author, who for many years has been in close contact with problems pertaining to the development of colonial agriculture, discusses the relative merits and shortcomings of the plantation versus peasant systems of agricultural production. To do this he uses as examples the Netherlands Indies, Malaya, Ceylon, Mauritius, Fiji, the West Indies, the Tropical African Dependencies, and the British Central and East African Dependencies. The history of the development of agriculture in each of these regions is briefly traced

followed with an analysis of the various factors that have contributed and led up to the present agricultural situation with its social and economic implications. The book for the most part is well written and agronomists and others will find much of interest in it.—R. J. GARBER.

Agronomic Affairs

THE STEVENSON AWARDS

DR. W. H. STEVENSON

DOCTOR W. H. STEVENSON of the Iowa State College, Ames, Iowa, and his wife, Rosaltha Scott Stevenson, have given the American Society of Agronomy funds for a five-year period from which to make two awards each year to members of the Society who have done outstanding research work. One of these will be awarded for research work in farm crops and one for research in soils. The annual awards are to consist of five hundred dollars ($500) each in cash and a suitable certificate of recognition. The donors wish in this manner to encourage and stimulate agronomic research, especially on the part of the younger members of the Society.

The Executive Committee of the Society has unanimously accepted this generous offer, and has expressed to Doctor and Mrs. Stevenson its appreciation in behalf of the Society.

The awards are to be administered by the American Society of Agronomy under rules approved by the donors and the Executive Committee of the Society. The following regulations have been adopted, and all awards will be made in accordance with these stipulations:

1. The recipients must be members of the American Society of Agronomy and shall have made outstanding scientific contributions or discoveries in the field of agronomy.

2. The awards are limited to citizens of the United States and Canada who are actively engaged in research.

3. No general officer of the American Society of Agronomy (or member of the Awards Committee) shall be eligible for the awards while holding such position.

4. The work on which an award is based may have extended over a considerable period of years, but must have been completed or be in progress within the five-year period preceding the year in which the award is made. Some reports of the research must already have been published in scientific channels within that period.

5. Total recent accomplishment in a certain field as well as research relating to a particular problem may be the basis for the award.

6. No individual shall receive an award more than once.

7. An award may be given to co-workers if this is deemed advisable by the Awards Committee; as, for example, to a research professor and one or more of his associates or graduate students.

8. Nominations for awards shall be made in writing to the Secre-

tary of the American Society of Agronomy before June 15 of the year in which such nominations are made.

9. All nominations, together with supporting materials, received by the Secretary shall be transmitted to the Chairman of the Awards Committee immediately after the closing date for nominations. The Committee shall report its selections for the year to the Secretary not later than November 1 of that year.

10. Any member of the Society in good standing (except members of the Awards Committee) may make nominations. No member may make more than one nomination in any one year.

11. All nominations must be accompanied by: (1) A brief biography of the nominee, (2) copies of publications which are based on the research, and (3) a statement of the value to agriculture and science of the work upon which the nomination is based.

12. The Awards Committee shall consist of five members. The Vice President of the Society shall be chairman of this Committee. The President of the American Society of Agronomy shall appoint the other members. In 1947 two members shall be appointed for a term of one year and two members for two years. Thereafter, two members shall be appointed each year for a two-year term. Any vacancies shall be filled by new appointees named by the President.

13. The decisions of the Awards Committee in the selection of recipients shall be final. If the Committee decides that none of the nominees is deserving of the award, no grants shall be made that year. But in no year shall the committee make more than two awards.

14. The presentation of the awards will be made at the time of the annual meeting of the American Society of Agronomy.

15. If recipients are selected, the first awards will be made in 1947.

Doctor Stevenson is a charter member of the American Society of Agronomy and was honored by election as a Fellow in 1931. Through a period of years while serving as Head of the Agronomy Department at Iowa State College he was active in promoting the interests of the faculty and in strengthening its program of activities.

He became a member of the staff of the Iowa Station as Professor of Soils in 1902. In 1910 he was made head of the Department of Agronomy (Farm Crops and Soils) and Director of the Iowa Soil Survey, continuing to serve in these capacities through a period of more than 20 years—until 1932. He was named Vice-Director of the Iowa Agricultural Experiment Station in 1912 and has continued in this capacity to the present.

In addition to his work in the field of agronomy, Doctor Stevenson served as permanent United States delegate to the International Institute of Agriculture at Rome in 1921–22 and as a special representative of the United States Government at the International Institute in 1924.

SPECIAL COMMITTEES NAMED FOR DEVELOPMENT OF THE ENLARGED PROGRAM

THE Executive Committee has authorized the appointment of special committees to put into effect the recommendations of the Committee on Policy and Program which received an overwhelming vote of approval in the mail ballot conducted recently. President W. H. Pierre has therefore named the following committees to implement the enlarged program.

DEVELOPMENT AND ENDOWMENT FUND

Emil Truog, *Chairman*
G. B. Bodman
R. Bradfield
R. H. Bray
H. E. Brewbaker
J. A. Chucka
W. A. Albrecht
W. O. Collins
R. W. Cummings
H. L. Dunton
F. L. Duley
E. A. Hollowell
C. D. Hoover
H. L. Garrard
G. D. Scarseth
F. B. Smith
John R. Taylor
S. C. Vandecaveye
C. J. Willard
G. G. Pohlman
H. B. Siems

AGRONOMIC EDUCATION

H. K. Wilson, *Chairman*
O. T. Coleman
K. H. Klages
L. M. Turk
H. E. Myers
G. C. Klingman
W. C. Libby
G. H. Dungan
D. W. Thorne

AGRONOMIC APPLICATIONS

Grover F. Brown, *Chairman*
W. A. Albrecht
Horace Cheney
E. H. Frolik
Fred Grau
A. L. Hafenrichter
H. J. Harper
G. N. Hofer
J. C. Lowrey
H. H. Tucker
Vernon A. Young

REGIONAL BRANCHES

Russell Coleman, *Chairman*
G. K. Middleton
S. S. Obenshain
T. E. Odland
P. R. Miller
D. R. Dodd
Harold Myers
S. P. Swenson
Omer Kelley
J. B. Harrington
Alfred Leahy

NEW PUBLICATION

Karl S. Quisenberry, *Chairman*
J. E. Adams
F. W. Parker
Grover Brown
J. R. Taylor
John H. Parker
Paul Stewart
F. E. Bear
C. F. Simmons
J. D. Luckett
H. D. Hughes

REVISION OF CONSTITUTION AND BY-LAWS

F. W. Parker, *Chairman*
C. E. Marshall
S. P. Swenson
R. D. Hockensmith
W. H. Leonard
J. C. Lowery
C. H. Serviss

ALFALFA IMPROVEMENT CONFERENCE

THE Central Alfalfa Improvement Group is planning to hold a meeting in Manhattan, Kansas, on June 10th, in combination with the summer meeting of the Corn Belt Section of the Society. Doctor C. P. Wilsie of Iowa State College is Chairman of the Group, Professor C. O. Grandfield of Kansas State College is Vice Chairman, and Doctor H. R. Albrecht of Purdue University is Secretary.

BOOKS AND WORLD RECOVERY

THE desperate and continued need for American publications to serve as tools of physical and intellectual reconstruction abroad has been made vividly apparent by appeals from scholars in many lands. The American Book Center for War Devastated Libraries has been urged to continue meeting this need at least through 1947. The Book Center is therefore making a renewed appeal for American books and periodicals—for *technical and scholarly books and periodicals in all fields* and particularly for *publications of the past ten years*. We shall especially welcome complete or incomplete files of the JOURNAL of the American Society of Agronomy.

The generous support which has been given to the Book Center has made it possible to ship more than 700,000 volumes abroad in the past year. It is hoped to double this amount before the Book Center closes. The books and periodicals which your personal or institutional library can spare are urgently needed and will help in the reconstruction which must preface world understanding and peace.

Ship your contributions to the American Book Center, c/o The Library of Congress, Washington, 25, D. C., freight prepaid, or write to the Center for further information.–THE AMERICAN BOOK CENTER.

NEWS ITEMS

DOCTOR CLARENCE F. GENTER became Associate Agronomist in charge of the Corn Breeding work at the Virginia Agricultural Experiment Station, beginning February 1. Doctor Genter replaces Doctor P. M. Phillippe, who recently resigned to accept a position at the University of Kentucky. Doctor Genter came to Virginia from the position of General Manager and Director of the Illinios Seed Producers Association at Urbana. His training in agronomy was at Michigan State College and Ohio State University.

—A—

CHARLES I. RICH became Assistant Agronomist in Soil Fertility investigation at Virginia Polytechnic Institute February 10. He replaces John Pendleton, who transferred to a full-time position with the College as Assistant Professor of Agronomy January 1. Mr. Rich is a graduate in agronomy of the University of Wisconsin, 1940, and received his M.S. from Virginia Polytechnic Institute in 1941. He spent three years, 1942–45, in meteorological work with the Army, and was employed by the Soil Conservation Service before entering the Army and after returning, until he accepted the position at Blacksburg.

PRESIDENT TRUMAN has called a conference on fire prevention to be held in Washington May 6, 7, and 8. Major General Philip B. Fleming has been named General Chairman and the conference is expected to draw over 2,000 representatives of federal, state, county, and municipal governments and business and civic organizations with a basic interest in fire prevention.

American Society of Agronomy JOURNAL

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Balanced Farming in Missouri[1]

ARNOLD W. KLEMME[2]

DURING the past 30 years farmers throughout Missouri and the nation have greatly improved their farming methods by the widespread adoption of improved practices found through the research of experiment stations and presented to them through the agricultural extension service. Much of the high level of production through the war years can be attributed to the wide use of these improved practices. In the past, in Missouri as in other states, information has been disseminated in the main on the basis of projects or individual practices, leaving it largely to the individual farmer to coordinate these practices into a well-balanced farming system. Some farmers have been able to make this coordination and to use the information advantageously. Other farmers have put into use one or more practices not fully realizing that the fullest economic benefits can be obtained only by the adoption of all essential practices related to the individual farm.

The close interrelationship of the various practices and the need for their coordination is well illustrated by the livestock enterprise from which Missouri farmers receive approximately 80% of their income. A successful livestock enterprise requires the coordinated use of several practices.

For example, an ample supply of high quality feed year in and year out is the first prerequisite. To grow sufficient feed to feed properly the livestock required to furnish sufficient income for a satisfactory living on the average Missouri farm necessitates high acre yields and quality crops. To accomplish this goal, maintenance of a high soil fertility level, good soil drainage, the wide use of systematic crop rotations including legumes, and the best adapted varieties and cultural methods are required. Of equal importance for maximum economic returns is production bred livestock capable of efficiently utilizing the feed produced and giving high production per unit. Diseases and parasites must be kept under control: A clean water supply and adequate shelter must be provided. To practice hog sanitation and have protein and mineral rich forage for hogs, a crop rotation including legumes must be used.

[1]Contribution from the Extension Department, University of Missouri, Columbia, Mo. Presented as part of the Extension Program at the annual meeting of the Society held in Omaha, Neb., November 21, 1946. Received for publication December 26, 1946.

[2]Extension Professor of Soils and Chairman, Missouri Balanced Farming Committee.

Numerous surveys show that the failure to use such rotations, along with the lack of clean water in the fields, is responsible for many farmers' inability to realize economical production.

A soil conservation and improvement program may be established on a farm and a material increase in production of crops brought about. Unless the management of the livestock enterprise is such as to utilize this feed for the highest possible production per animal unit, little or no increase in income may be obtained. Without additional net income, the soil conservation and improvement program will lose its chief motivating force and likely will be abandoned sooner or later.

These examples are sufficient to show that there is a close interrelationship between the various practices used on the farm. For best results, the information from the various departments of the college of agriculture must be correlated and used in a systematic program, or, what we in Missouri call a balanced farming program. While the individual farm practice approach will need to be continued to attract attention and develop interest, the complete balanced farming approach is ideally suited for farm families who are using one or more approved practices.

WHAT IS BALANCED FARMING?

From the farm family's viewpoint, balanced farming is simply a method of coordinating all the approved practices ssuited to the individual farm and family into a well-balanced farming system so as to achieve efficient production, high net income, the conservation of soil, and other resources and a more satisfactory living for the farm family.

From the extension or other field worker's viewpoint it is a way of coordinating the various activities of field workers so as to make their work most effective.

Balanced farming includes planning and putting into operation by the farm family, with the technical assistance of the Missouri Agricultural Extension Service and other field workers, the following:

1. Soil treatments and other soil conservation practices necessary to produced high acre yields and quality crops and to maintain soil resources.

2. Well-balanced crop rotation systems to provide adequate pasture and roughage, and such grain as the farm is suited to produce.

3. A field layout which suits the farm and which facilitates the use if the recommended rotations.

4. A water management system designed for the entire farm. This includes the use of terraces and structures to control erosion on rolling land, drainage where needed, and deep ponds to furnish clean water on livestock farms.

5. Livestock enterprises and management practices that utilize most profitably the production of the cropping system.

6. Most efficient utilization of labor, power, machinery, woodlands, wildlife, and other resources.

7. Home improvement practices.

8. Wise use of available and borrowed capital to put the approved practices into operation to the best advantage.

9. Sufficient financial records to keep all operations on a sound, businesslike basis.

FIRST STEP IS A PLAN

The first step in the development of a balanced farming system is the preparation of a written plan. The plan serves as a guide for future operations to insure effective coordination of the best known farming practices into a balanced system for the farm and home.

The College of Agriculture's Extension Service provides for both the farm and home, work books for recording the plan and handbooks containing information, for use as a reference for developing and putting the plan into operation.

The plan is started on the project where there is farmer interest. In some cases, that may be the farm home, such as a new water system, kitchen or other improvements. In most cases, however, it will be some project on the farm, such as water management, use of fertilizers, crop rotations, or livestock improvement.

In developing the farm plan a map of the present farm layout (Fig. 1) is made and put in the workbook. Frequently the farmer uses the aerial photo provided him by the Agricultural Adjustment Administration. A land class map and a revised farm layout map (Fig. 2) are prepared showing a complete water management system, new field layout, lanes, retention pastures, and arrangement for hog and poultry sanitation and vegetable production. In the water management system terraces and terrace outlets are planned along established fence lines, as far as possible, so that many field ditches can be completely removed and that farm fields can be entered with farm machinery without crossing terraces. Where needed, drainage is also planned. The county agent or other field worker walks the farm with the farmer and advises on land use and other practices needed.

In groups, or individually, farmers are aided in planning crop rotations for the revised system (Fig. 3), considering the suitability of the land for different crop uses, kinds of livestock and cash crops to be produced, needs for pasture, roughage, grain, available labor markets, and other facilities. These usually include short rotations of crops, such as corn, small grain, clover or alfalfa, which draw heavily on soil fertility on the most fertile fields. So far as possible, the fields designated for the production of alfalfa or silage are located near the barn or silo to reduce labor. Other crops which require less fertility are designated for the less fertile lands. Steep slopes and areas less suitable for cultivated crops are used for permanent pasture or meadows. Soil treatments based on soil tests and other soil and agronomic factors to give high acre yields and quality crops are included in the plan and their use calendarized.

Assistance is given in checking these rotations as to the average annual production that can be expected of pastures as measured in livestock carrying capacity (Fig. 4), tonnage of hay and bushels of

grain (Fig. 5), and the kind and number of livestock the feed produced will support. Another check is made of the influence of the water management system, soil treatments, and crop rotations on maintaining the productivity of the soil as outlined in Missouri Experiment Station Bulletin 405. Then the procedure and cost of putting the plan into operation are calendarized and itemized.

The potential income based on average price levels from 1925 to 1939 is estimated. Unless the plan gives higher net income and yet

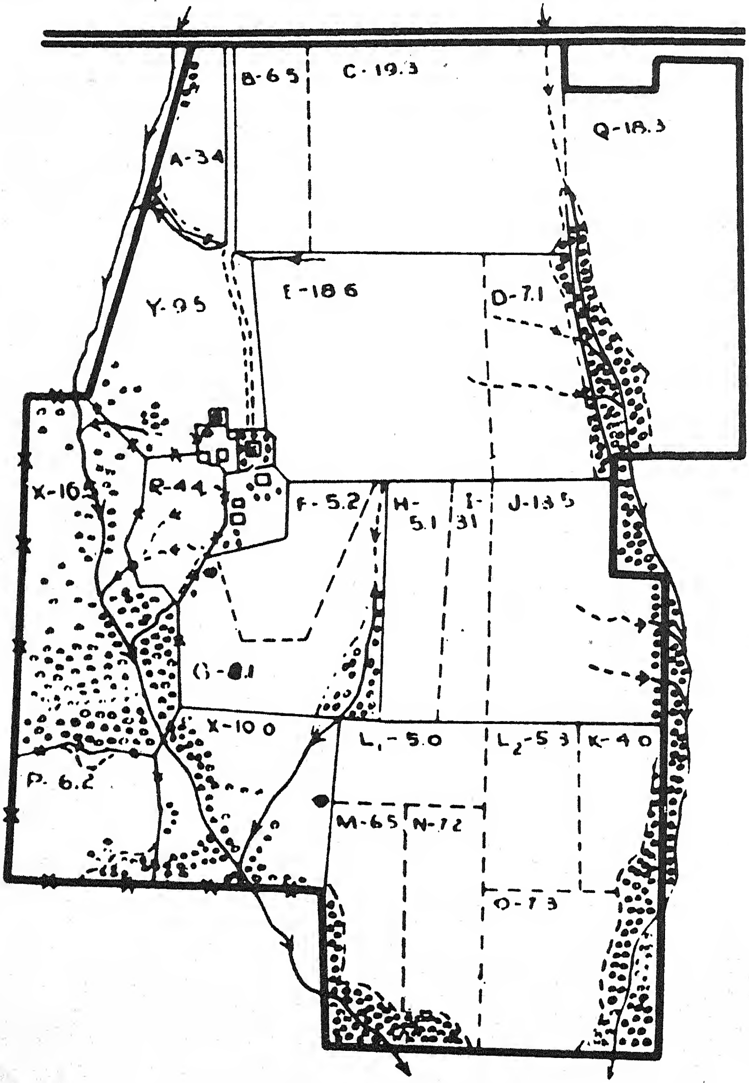

FIG. 1.—Original farm layout in 1935.

maintains soil fertility, adjustments are made so as to meet these requirements. Some illustrations of these checks are attached.

BALANCED FARMING ACCELERATES ADOPTION OF AGRONOMIC AND CONSERVATION PRACTICES

An example of how the balanced farming method of approach

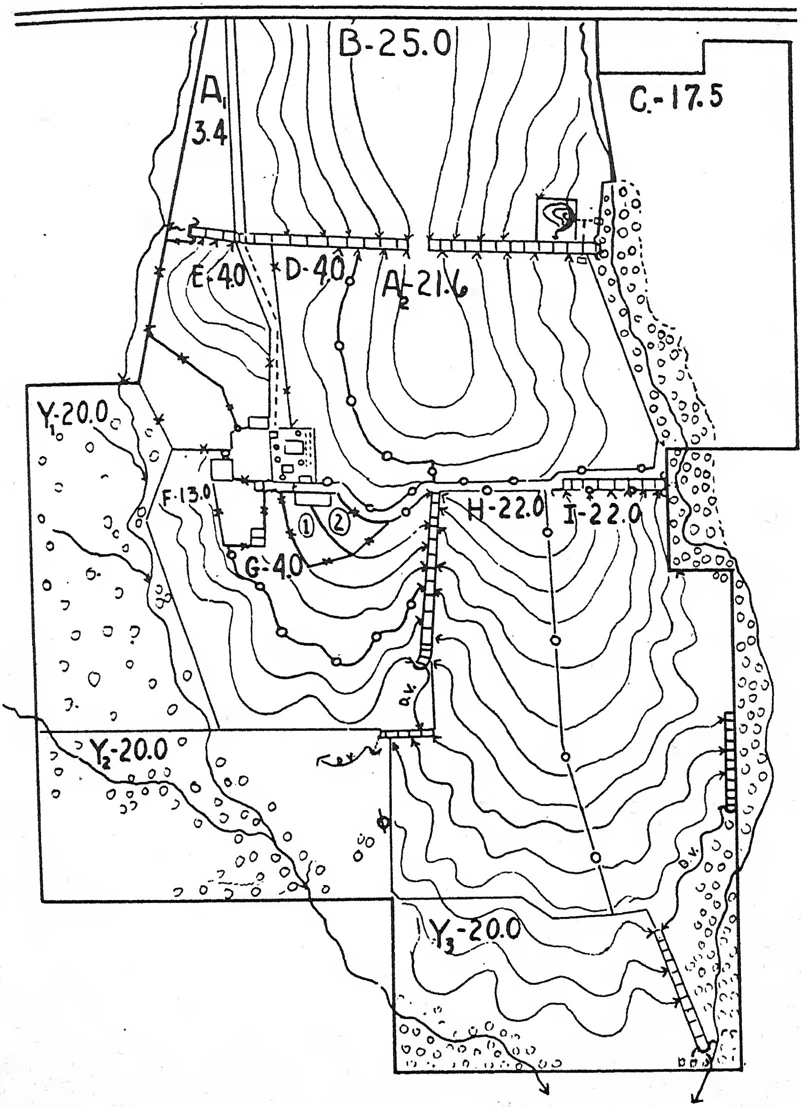

FIG. 2.—Revised farm layout with a balanced farm program in operation. Changes in field arrangements have been made and a water-management system put in operation.

increases the adoption of agronomic, conservation, and other practices is shown by the activities of the 46 Carroll County farms which were enrolled in a balanced farming association in 1946. In 1945, these 46 farmers used 1,000 tons of limestone, 125 tons of fertilizer, constructed three terrace outlets, and 8½ miles of terraces.

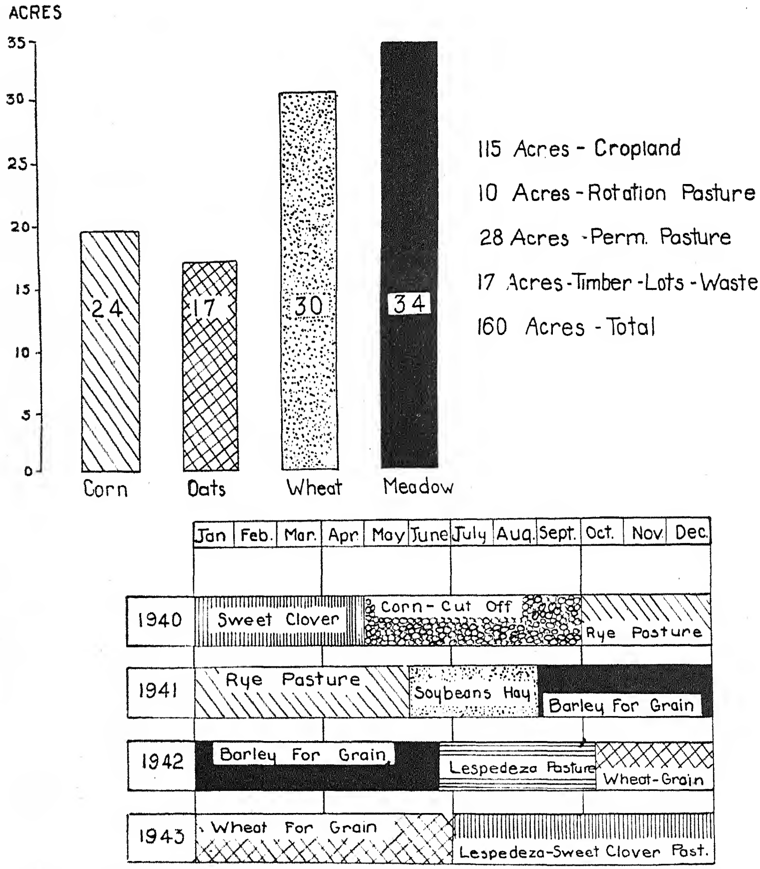

FIG. 3.—Original cropping system as in 1935 (above) and revised cropping system, with major and supplementary crops in rotation. Rotations are planned and put into operation in accord with best land use practices and which will give maximum production of high-quality crops.

(See Figs. 6 and 7.) In 1946, after enrolling in a balanced farming association, definite crop rotations were established on all the farms, 1,200 tons of limestone and 350 tons of fertilizer were used. Seventy-five terrace outlets and 80 miles of terraces were constructed. In 1945, only three of these farmers raised hogs and poultry on clean ground. In 1946, 20 of them raised their hogs and poultry on clean ground.

BALANCED FARMING PAYS

Balanced farming demonstrations have been in operation in Mis-

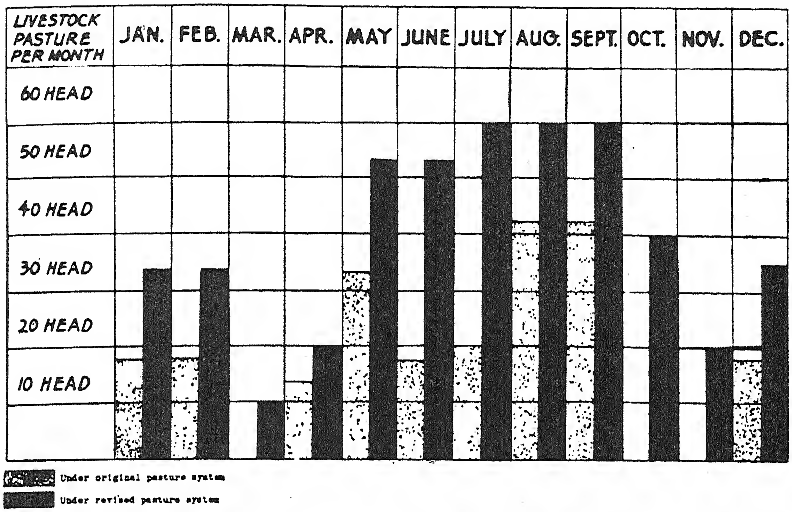

FIG. 4.—Carrying capacity of pastures under original and under revised farming system.

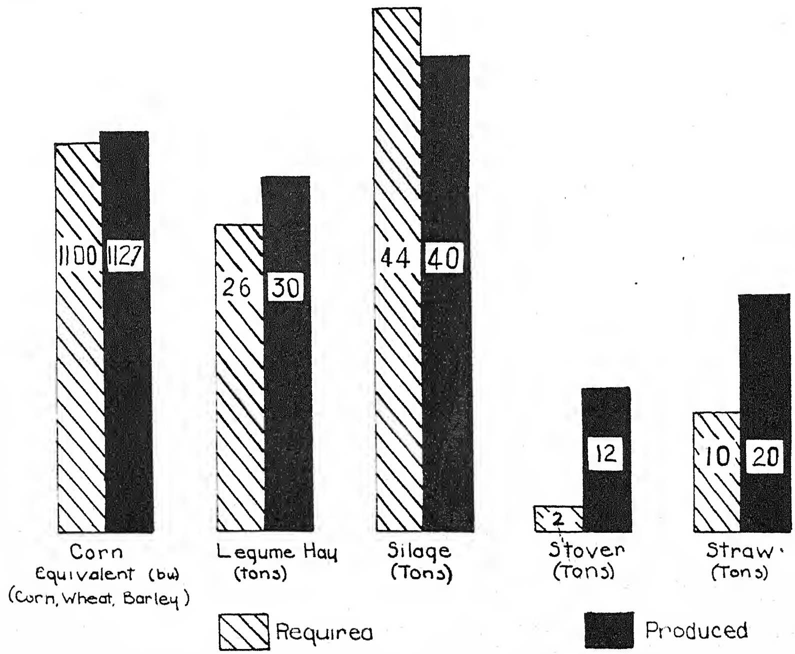

FIG. 5.—Grain and roughage balance under the revised system. Green succulent pasture eight to nine months of the year along with ample high-quality roughage as well as grain are produced in a balanced farming system.

souri for 10 years. They show conclusively that the application of the principles of this program pays big dividends. Records on 10 dairy farms in Warren county, in central Missouri, show that feed production was increased enough to care for one-third more dairy cows within a 4-year period after the program was initiated. More important still, butterfat production per cow was increased 46%.

The Charles Schaffer balanced farm demonstration in Lafayette County, in northwest Missouri, shows clearly the value of this program. During the 4-year period 1938–41, the livestock carrying

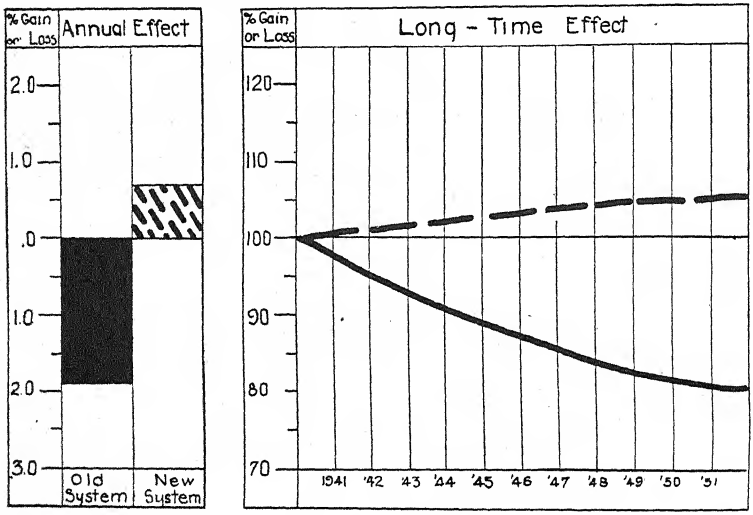

FIG. 6.—Showing productivity balance. Actual soil conservation and the improvement of soil fertility is accomplished in a balanced farming program.

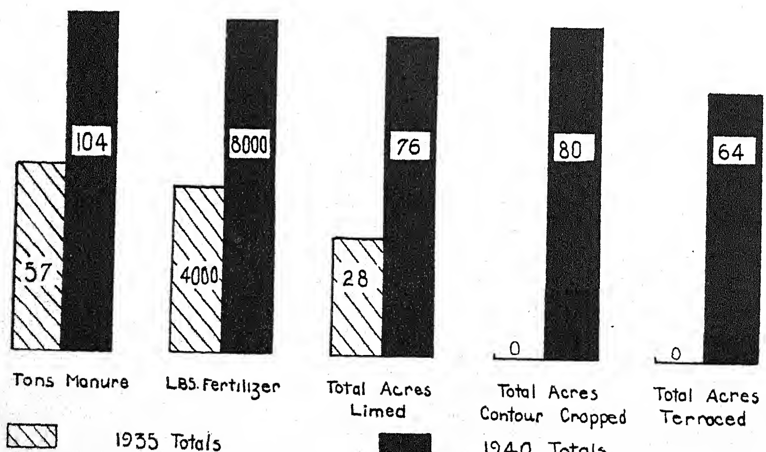

FIG. 7.—Good soil management practices are used which will replace the scarce nutrients removed by crops and provide an ample turnover of soil fertility for high acre yields of quality crops.

capacity was increased from 15 Hereford cows to 40, and the net cash income from $1,150 to $2,246.

Similar results were obtained by Max Mauss in a balanced farming demonstration in the Central Missouri Ozarks. During the 5-year period 1937–41, he increased his Jersey milking herd from 11 to 17 cows, with a four-fold increase in milk production and an increase in annual net income from $795 to $2,375. (See Figs. 8 and 9.)

The records of these and numerous other cooperators have been responsible for the development of a statewide balanced farming

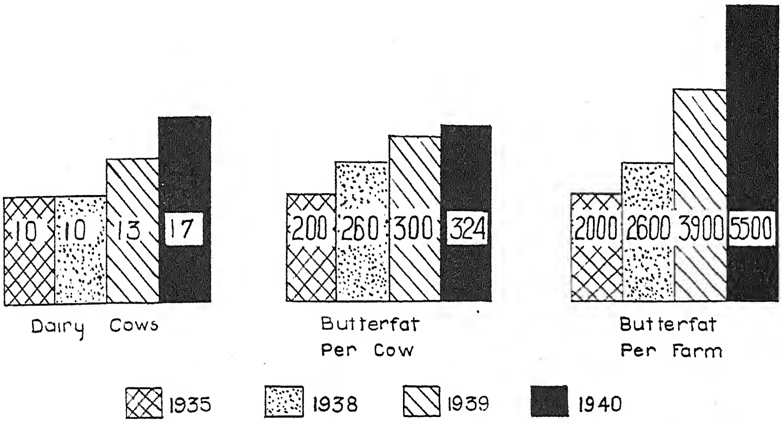

FIG. 8.—Changes in livestock production under the revised system. A balanced farming system enables the operator to handle more and better quality livestock.

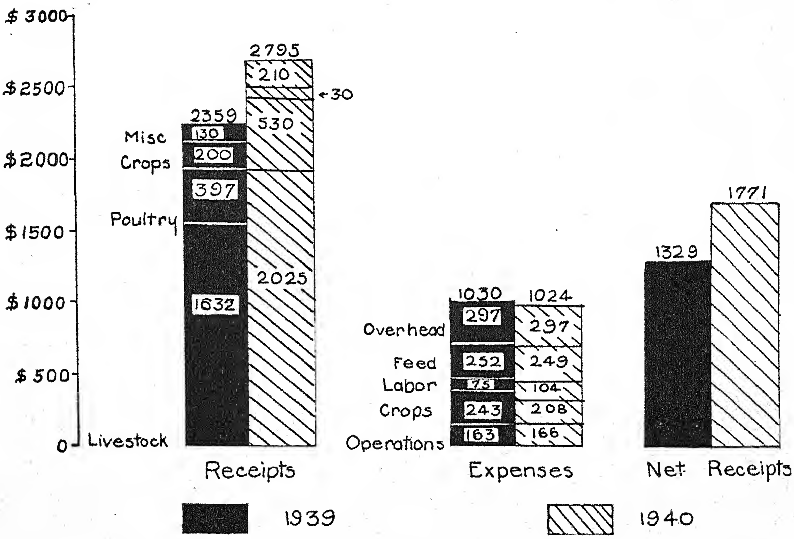

FIG. 9.—Actual financial results of a balanced farming system show increased net receipts for the operator.

program. Over 5,000 farms now have the program in partial or full operation.

EXPANDING THE PROGRAM

Training county agents and others.—All Missouri county agents have been given special training in the procedure of doing balanced farming. Sixty-five assistant county agents were trained and placed in the counties the past year. These men are giving from part to full time on the balanced farming program. Home demonstration agents were given similar training in the home phase of the program.

Contractors have been given special training in planning water management systems—constructing terraces and terrace outlets.

Teachers of veterans trained to use balanced farming procedure.—A series of training meetings were held during the fall for teachers of veterans enrolled in placement training in agriculture. These teachers are using the balanced farming program.

Tenant purchase farmers of Farm Security Administration cooperate.—The tenant purchase farmers of the Farm Security Administration are setting up balanced farming systems. Many of them have the plans well into full operation.

Soil district technicians help.—In the 18 counties which have Soil Conservation Districts, soil conservation technicians cooperate with the county agents in developing water management and agronomic phases of balanced farming. The county agents then further develop the livestock and home phases of the program.

Balanced farming associations in operation.—Two balanced farming associations in which cooperating farmers financed half or more of the cost of employing an associate county agent to give them specific assistance operated during the past year. Each of these associations has from 40 to 50 cooperating farmers. The associate county agent devotes his full time to these farmers, assisting them in setting up plans and putting them into operation. Additional associations are being organized.

Business groups cooperate.—Business groups give excellent cooperation to the balanced farming program. Business interests in southwest Missouri appropriated $15,000 to the local county farm bureaus for the employment of assistant county agents to work on the balanced farming program. The Missouri Bankers Association is awarding special county awards to the farmers enrolled in the balanced farming program who make the greatest progress. The Kansas City, St. Louis, and Springfield chambers of commerce are making county and district awards for the best balanced farming programs.

Farm organizations provide facilities.—The Missouri Farmers Association and Sanitary Milk Producers Association have established artificial breeding associations to aid dairy farmers in developing higher producing dairy stock. The Missouri Farm Bureau Association is financing the establishment of soil testing laboratories.

IS BALANCED FARMING TOO SLOW AND EXPENSIVE?

Some of the objections raised to the balanced farming method of doing extension work are that it requires too much personal service, and therefore, it is too slow and expensive.

It *does* require personal service—the kind that gives the farm family specific information about their own farms, not generalities which may or may not apply. One county agent establishes and helps put into partial operation the program on 40 to 50 farms per year.

In a balanced farming association the special county agent works with one group of 50 farm families from 1 to 2 years, and is then shifted to another association.

After the plan is made and partially established, and the farm family is thoroughly familiar with it, the regular county agent's office will provide the information for servicing and replanning as necessary to meet changing conditions.

In a 10-year period, one trained worker will be able to establish plans and assist in putting them into operation on 400 to 500 farms. In this period, three such workers will be able to reach, with this balanced farming program, one-half to three-fourths of the farms in the average Missouri county.

Provides numerous project demonstrations.—On farms with balanced farm plans in operation there are various project demonstrations which can be used for teaching others. For example, there are demonstrations of adapted varieties of crops, recommended soil treatments, production bred livestock, each in its proper place in a farming system. Such demonstrations are more effective than single project demonstrations.

Financing the balanced farming associations.—In the balanced farming association the farmer pays part of the salary of this worker, the remainder coming from public funds and others interested in agriculture. The cooperating farmer paying part of the cost helps to assure his interest and cooperation.

Well-trained personnel essential.—For this program to be successful, a well-trained field personnel is essential. They must be good teachers who can talk, plan, and work with the farm family. These well-trained teachers find keen students in the farm family. Both the field worker and the farm family learn and develop together. This program, we believe, points a way to a better Missouri agriculture.

The Winter Grazing Program in Alabama[1]

J. C. Lowery[2]

THE winter grazing program in Alabama is one of the most important factors in the state's rapidly changing agriculture. Land is being used for productive purposes in winter as well as in summer. Labor of harvesting, storing and feeding is saved. Need for storage space is reduced. More dairy cows and other kinds of livestock can be produced. Farmers find winter grazing a good way to use some of their land that cannot be planted in cotton or other cash crops.

Only about one acre out of five on a very high percentage of the farms is used for production of cash income.

Although the winter grazing program is one of the most sensational developments in Alabama agriculture in recent years, the acreage is far too small to meet the needs. The program is still in early stages of development.

The following figures for 1945 indicate size of the program:

Kind of Crop	No. of Farmers	Acres
Crimson clover alone	5,686	23,537
Crimson clover and ryegrass	4,451	33,222
Small grain mixtures	17,929	118,827
Caley peas	2,258	99,009
Red clover	57	824
Bur clover	197	2,290

HOW HAS THE PROGRAM BEEN DEVELOPED?

The development has been by the long-established practice of Land-Grant Colleges. Thst is, research has been the foundation for meeting an acute winter feed need. The full story of the basic research cannot be covered in this discussion.

It should be pointed out, however, that the Alabama Experiment Station had been conducting pasture experiments over a long period. Years ago the station had accumulated a certain amount of information on pasture improvement.

Up to the depression years it was difficult to create much interest in pasture improvement. Farmers were primarily engaged in cotton production. It was very hard to establish clear-cut pasture improvement demonstrations.

It had been the experience of the extension agronomist that a well-planned program consistently followed, year after year, got the best results. Therefore, in 1935, when farmers were having to make many most difficult adjustments a pasture improvement program was planned, to extend over a long period of years. The Experiment Station on several new substations was beginning to release additional pasture information of great practical value.

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[1]Contribution from the Extension Department, Alabama Polytechnic Institute, Auburn, Ala. Presented as part of the Extension Program at the Annual meeting of the Society held in Omaha, Neb., November 21, 1946. Received for publication December 26, 1946.

[2]Extension Agronomist.

The goal of the new pasture program set in 1935 was one improved pasture demonstration in each agricultural beat in the state.

In 1935 the Unit Test Demonstration farm program was begun through a memorandum of understanding between the authority and the college. Pasture improvement was made a basic part of whole-farm land use and cover program in these demonstrations. From 1935 to 1941 much new information came out of these demonstrations. In the early days pens were built on the treated and untreated areas, clippings were made, weights taken, and many chemical analysis made of the pasture plants.

Interest in pasture improvement developed rapidly as a result of these demonstrations. Pasture improvement had become one of the most popular practices. County agents reported more questions about pasture improvement than about any other problem. In some counties the pasture inquiries exceeded all other combined.

Although use of supplementary grazing crops had been a part of the pasture improvement program, the major interest from 1935 through 1940 had been with permanent pastures.

Under climatic conditions permanent pastures furnish little grazing in the winter. In all of the early pasture demonstrations the need for winter grazing stood out as a major problem.

A winter grazing program was worked out at the substation in the Black Belt area, based on use of caley peas *Lathyrus hirsutus*, frosted Johnson grass, small grain, and winter clovers.

At the Tennessee Valley substation a winter grazing program for dairy cows was developed whereby grazing was practically the sole source of feed. The winter crop is a combination of crimson clover and Italian ryegrass. Release of this and other research and experience with demonstrations enabled the Extension Service to revise the educational program with pastures.

The pasture program was placed on the basis of an "All-Year Pasture System". By this is meant full use of supplementary grazing crops for summer and winter.

A circular entitled "All-Year Pasture System" was published in 1943 and a revised edition published in 1944. In this process of streamlining the pasture project winter grazing demonstrations were established wherever feasible. Winter grazing demonstrations became a feature on most of the Unit Test Demonstration farms. As with other problems, we worked on the principle that the basic first step is good demonstrations by soil areas, size, and type of farms so people can see results.

In beginning this program conferences of county agents and assistant agents were held at substations to acquaint them fully with research results. In 1940, the work was quite largely confined to those farmers to whom the county extension workers could give close supervision. Under Alabama rainfall conditions, success is quite dependent on preparation of land, fertilization, and date of seeding.

In the winter of 1943–44, demonstrators were pleased with winter grazing because it saved them so much feed, labor, and storage space.

Farmers found winter gazing very helpful in meeting their feed needs under war conditions.

In the spring of 1944, a careful survey on Unit Test Demonstration farms and other demonstrations was made to determine actual results to farmers. In the Tennessee Valley Watershed area demonstrators got an average of 111 days of gazing in the period October to May, inclusive. The value of feed saved averaged $16.97 per acre. Demonstrations south of the Tennessee River Watershed area averaged 106 days grazing for the October to May period. Value of feed saved ranged from $13.85 to $48.34 per acre, depending on kind of soil and type of livestock grazed. In both areas milk production was increased during the winter months.

Similar information was collected in 1945. This material and further work by the Experiment Station provided a wealth of material for educational purposes.

Unit Test Demonstration farmers, dairymen, cattle producers, general farmers, and business and professional men attended winter grazing meetings at the substations.

County agents concentrated on local tours and field meetings during the fall and winter months. It is desirable to hold these meetings from November 1 to March 1—the critical period for grazing.

In a series of conferences with the fertilizer industry in the summer of 1942 an appeal was made for the industry to make fertilizer available for winter grazing crops. The response was good. Fertilizer companies were urged to boost winter grazing in their advertising program. This resulted in extensive spreading of information about winter grazing. The extension agronomist aided several firms in preparation of copy.

One company published a beautifully illustrated folder, in color, carrying winter grazing recommendations and the slogan "June Grazing in January". The slogan quickly became popular and has been very effective in stimulating interest.

A set of color slides was made on the demonstrations in 1944. Duplicate sets were furnished all county agents.

Success stories have been extensively used in community meetings, circular letters, and newspapers.

County agents have been quite successful in getting cooperation from business houses in running advertisements featuring winter grazing. Milk plants and others have distributed Extension publications to their customers as a part of the county agents educational program. County agents in many counties have followed a definite system of visiting demonstrators and other farmers to help them with winter grazing problems.

The extension agronomist keeps counties supplied with special circulars and other material dealing with winter grazing. The acreage of winter gazing is small compared to needs and opportunities. Progress over the past 4 years is very encouraging. Farmers are saying they can make a winter pasture easier than they can make a summer pasture. In one county where special emphasis was placed on green grazing in winter for the family milk cows, many farmers and their

wives said they had more of the best milk they had ever had in the winter. This means better living.

Winter grazing is the most popular project of recent years. Winter grazing, we believe, will become one of Alabama's most important crops within a few years.

The success of the program is due to research to meet a problem and clear-cut demonstrations conducted by the Extension Service and effectively used in teaching.

Pasture Improvement—Methods of Getting the Job Done[1]

F. V. Burcalow[2]

PASTURE improvement is of utmost importance in Wisconsin because over 12 million acres of the 22 million acres of land in farms in Wisconsin is classified as pasture. Less than 3 million acres of this total of 12 million acres are classified as plowable pasture, the balance being so-called open permanent pastures or woodland pasture. Much of the open pasture land is on steep or rolling side hills very subject to erosion if cultivated. Improved pasture production is also of utmost importance because 88% of the total farm income in Wisconsin is derived from the sale of livestock and livestock products.

Extension work on the improvement of so-called permanent pastures in Wisconsin was started as a major project in 1935. Interest in this improvement resulted from severe damage to millions of acres of bluegrass by white grubs. They did such a complete job of eliminating the bluegrass that livestock production was greatly reduced and the pastures became badly infested with weeds. As a result of some preliminary work started in 1923 by Professor L. F. Graber, the program now known as renovation was ready for extensive use by 1935. This program is based on the establishment of drought-tolerant legumes in old bluegrass pastures without plowing. Briefly stated, the steps in this renovation program consist in testing the soil, applying the necessary lime and fertilizer, preparing a seedbed by use of a disk, spring tooth, field cultivator, or a combination of these implements, and reseeding these pastures to a mixture of sweetclover, red clover, and timothy. This was the basis of the extension program started in 1935 and 1936 on individual farms scattered throughout the grassland areas throughout Wisconsin. Considerable supplies of TVA phosphate and potash from the American Potash Institute were made available to local cooperators who agreed to do the necessary work and provide the lime and seed for the job. These demonstrations were carried on under the direction of extension specialists in cooperation with the county agents and Soil Conservation Service personnel where they were available. Method demonstrations were held at the time the work was done and the result demonstrations held in subsequent years at these sites.

A total of some 500 demonstrations were established in the years 1935, 1936, 1937, and 1938. These demonstrations were used as stopping places on county extension tours as well as for individual meetings. This field work was supplemented by discussions on pasture improvement at winter meetings as well as preparation of circulars, news stories, and radio broadcasts on this subject. By 1938

[1]Contribution from the Extension Department, University of Wisconsin, Madison, Wis. Presented as part of the Extension Program at the annual meeting of the Society held in Omaha, Neb., November 21, 1946. Received for publication December 26, 1946.

[2]Extension Agronomist.

adequate experimental evidence on the value of bromegrass and alfalfa was at hand to justify changing the recommendation to a mixture of bromegrass, alfalfa, and red clover in place of the original mixture of sweetclover, red clover, and timothy.

Similar demonstrations but of a lesser number have been established each year since 1938. Yield records in terms of cow pasture days as well as dry weight data obtained from use of cages were secured from a portion of these demonstrations. The data from these demonstrations were supplemented or substantiated by an extensive 5-year research program in Richland County on this type of pasture work which showed a double production over a period of five years following the initial treatment, or $3.00 per ton cost of increased pasture feed as a result of renovation.

In spite of these extensive demonstrations and accompanying publicity, farmer acceptance of this practice was much slower than desired. Lack of help and adequate machinery and scarcity of seed and fertilizer in adequate amounts were pertinent factors in the slow acceptance of this program, but undoubtedly factors of equal importance are lack of appreciation on the part of farmers of the importance of good pastures and the lethargy on the part of farmers to consider pastures as a crop worthy of the same managerial and cultural practices which he was in the habit of following with cereal or cultivated crops. One reason why farmers are slow in appreciating the value of improved pastures is because at present there is no satisfactory means, in terms which a farmer can understand, of expressing the production from pastures as related to production from crops such as grain, corn, or hay that he is in the habit of measuring in terms of bushels or tons per acre. We have unsuccessfully tried to get our farmers to use a measure of cow pasture days, pounds of dry feed, or total digestible nutrients per acre and other similar methods. We are still looking for a way to measure the production of pastures in terms of dollars or pounds of livestock or livestock products per acre. Although we appreciate this need, we do not have a satisfactory answer at the present time.

A new method of approach was inaugurated in the spring of 1946. Because pasture work is more than just agronomic, a college Grassland Committee was organized consisting of representatives from the Departments of Agronomy, Soils, Animal and Dairy Husbandry, Agricultural Engineering, and Agricultural Economics. This committee adopted the slogan "More land in grass more of the time—some land in grass all the time". Grassland agriculture is considered as a way of farming whereby more of the land is in grass more of the time, some land is in grass all of the time—where grass is considered as a crop worthy of the same managerial and cultural practices that have formerly been used in cereal and cultivated crops, and is a way of farming whereby perhaps 80% of the total feed for our livestock comes from improved pastures, high-quality hay, and grass silage. It is a way of farming in which emphasis should be placed on the harvesting and utilization of high-quality forages as well as on the production of high-quality forages.

The committee decided that the best way to convey its concept of grassland agriculture to the largest number of farmers in the shortest period of time would be through a series of Grassland Field Days held throughout the more important grassland areas of the state. A series of nine such field days were held throughout the last three weeks. of June in 1946. Before this proposition was taken to the counties concerned, a tentative program for the day was developed and discussed with the farm implement representatives in the state to secure their cooperation in making these days successful.

From three to five counties cooperated at each of these field days on a farm selected which had as many of the recommended practices in effect as possible, which was accessible by adequate highways, and large enough to handle the demonstrations and parking of automobiles. In most cases local civic organizations of one kind or another cooperated with the county agents and other agricultural agencies within the county, handling a multitude of details connected with such an undertaking. Local groups had committees on selection of farm, arrangements, parking, publicity, etc. The program for the day consisted of a so-called renovation cavalcade at 10:30 in the morning where from one to three acres of pature were used in demonstrating all of the steps in the renovation program. This was preceded by a very short discussion on the importance of improved pastures. Most of this discussion, however, took place while the actual demonstration was under way. This was possible by using a mobile public address system and the discussion continued while the truck spread lime over the area which was in turn followed by three or four field cultivators which in turn were followed by a tantem disk and a combination fertilizer-grain drill which put on the fertilizer and the recommended 8 pounds of bromegrass per acre mixed with a bushel of oats. The alfalfa, red clover, and Ladino clover seed was put on in the last operation by use of a corrugated roller with a grass seed attachment. With equipment made available by the implement dealers and cooperating farmers, this entire renovation cavalcade with the accompanying discussion took no longer than 45 minutes. Where circumstances permitted, recommended methods of gully control were also demonstrated to complete the morning's program.

Lunch was provided on the grounds, usually by FFA, 4–H, or some civic organization. Musical entertainment was provided locally until 1 o'clock when local committees and the host farmer were introduced by the county agent of the particular county who served as general chairman of the day. Following this the Dean gave a short talk on "What's Ahead in Grassland Agriculture". He was followed by a representative of the Agricultural Engineering Department who gave a short discussion on "What's Ahead in Forage Harvesting Machinery", but again most of this discussion took place during the actual demonstration of a hay crusher, buck rakes, field balers, various types of forage harvesters—harvesting both dry, wilted, and standing forage. Automatic unloading forage wagons were also demonstrated as well as various types of blowers used in

putting the forage into the barn or silo. During these demonstrations the pros and cons of grass silage and barn drying as a means of preserving high-quality forage were also discussed.

Better than 45,000 farmers attended these nine field days at which time they had an opportunity to see and hear recommendations relating to the production, harvesting, and utilzation of grass as a crop. It was also pointed out to them that good grass-legume mixtures in longer rotation was the most practical answer to conserving soil, not only conserving it but building up a reserve of organic matter in the soil so that when fields were occasionally plowed greater production of cereal or cultivated crops would result. A few more or less radical statements were made at these meetings purposely to get the farmers thinking—such statements as "There's no such thing as a permanent pasture" or "Bluegrass must be considered as a weed". These statements provoked much more thinking on the part of listening farmers than if they had been been expressed less radically. Wisconsin farmers greatly appreciated this type of field day and the thought has been expressed many times that it is of more value to Wisconsin agriculture to have the college bring these things out into the state where they can see them at close hand than it is to hope that more than a handful of farmers scattered from various areas of the state will ever get to the Station Days held on the university farm.

Many counties in Wisconsin which did not have these field days in 1946 are planning such events for 1947. In the counties where they were held in 1946 plans are presently being made to follow through on a smaller scale with a series of so-called forage clinics where individual questions can be handled better than is possible at the larger events. We have considerable reason to feel that the success of Grassland Field Days held in 1946 may perhaps set a new pattern for getting the job done by using a problem approach instead of a departmental approach.

Methods of Getting the Job Done on Soil Conservation[1]

D. E. HUTCHINSON[2]

THE ultimate aim in soil conservation programs should be complete programs of soil and water conservation and water utilization on all farms and ranches in the nation. Soil conservation is not new, but it was not widely applied by farmers until the soil conservation district idea was put into operation.

The present success of soil conservation districts can be attributed largely to two factors, *viz.*, (1.) the local management and administration of soil conservation districts by the farmers and ranchers, and (2.) the complete program of soil and water conservation being planned and applied on farms in soil conservation districts. It has been proved many times that one or two practices do not adequately do the job. It takes a combination of all known practices applied to the land.

As a background for the good relationship in Nebraska on conservation work, I would like to quote from a "Policy Statement on Relationships Between the Soil Conservation Service and the Agricultural Extension Service for Nebraska."

RESPONSIBILITIES IN EDUCATION AND INFORMATION

"In conjunction with both education and operations, the Extension Service and the Soil Conservation Service disseminate information to the public. This is a responsibility inherent in both organizations—in the Cooperative Extension Service under the Smith-Lever and supplementary acts and the memorandum of understanding with the state agricultural colleges; in the Soil Conservation Service under terms of the organic act of the Department of Agriculture and of the Soil Conservation Service Act (Public 46).

"It is the policy of the Soil Conservation Service and of the Extension Service to exercise this function on a basis of mutual assistance and cooperation as in part related in the Working Plan herewith attached, and agreed to by the Soil Conservation Service and the Nebraska Extension Service.

"It is the policy of the Soil Conservation Service to recognize the State Extension Service as the responsible agency and the primary channel through which agricultural information can be disseminated in the state and to work through it in the manner herein agreed in the release of information pertinent to soil and water conservation within the state.

"It is the policy of the Nebraska Agricultural Extension Service to recognize the Soil Conservation Service as an important source of information relative to soil and water conservation and to cooperate with the Soil Conservation Service in presenting soil and water

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[1]Contribution from the Extension Department, University of Nebraska, Lincoln, Neb. Presented as part of the Extension Program at the annual meeting of the Society held in Omaha, Neb., November 21, 1946. Received for publication December 26, 1946.

[2]Extension Soil Conservationist.

conservation information available from this source to the public of the state."

W. H. Brokaw, Director of the Agricultural Extension work at the College of Agriculture, University of Nebraska, tells us the Soil Conservation Service and the Extension Service must work as a *team* to accomplish the job of putting conservation on the land. The district conservationist of the Soil Conservation Service is brought into the picture in the educational phase before a soil conservation district is organized in a county.

It is not the responsibility of the Extension Service to organize soil conservation districts. The Service does have a responsibility to inform farm people of the need for soil and water conservation. The Extension Service also has a responsibility to tell landowners how they may help solve the problems of conservation through organization.

We feel a program to inform the people in a county of the benefits of conservation can best be carried on by having the local people set up a farmer committee to head up the educational program. These committees have functioned very well in the educational program toward district organization in Nebraska.

The job of getting complete programs of soil and water conservation on the land can be divided into two general classes. Those practices which require on-site assistance, and those upon which something can be done by educational means, including the maintenance of practices established by on-site assistance.

Those practices requiring on-site technical assistance are largely the responsibility of technicians assigned to soil conservation districts in those areas where districts are organized. Such practices in Nebraska may include laying out of terraces, diversions and contour lines, surveying farm ponds, designing gully control structures, surveys for drainage and irrigation surveys, laying out contour tree plantings, and surveys for diversions.

Those practices on which much can be done from an educational standpoint are grassed waterways, probably our No. 1 conservation need in Nebraska; land retirement, rotations, residue management and stubble mulch farming, range and pasture management, proper application of irrigation water, maintenance of terraces and grassed waterways.

The State Soil Conservation Committee in Nebraska, consisting of the Director of Agricultural Extension, Director of the Experiment Station, and Director of the Conservation Division of the University, request an annual work plan from each conservation district board of supervisors. The educational section is an important part of this annual work plan. We suggest this work plan be made jointly by the conservation district supervisors, the county extension agent, and the Soil Conservation Service technicians.

METHOD DEMONSTRATIONS

One of the important phases of the educational program in Nebraska, carried on jointly by the Soil Conservation districts and the

Extension Service, has been the holding of method demonstrations on converting gullies to grassed waterways, terrace construction with farm equipment, subsurface tillage farming, grass seeding, mechanical tree planting, and proper irrigation methods.

This type of demonstration or meeting is applicable whether you have 10 farmers or a thousand in attendance. At some of these demonstrations, two or more practices are demonstrated as grassed waterway development, terrace construction, and subsurface tillage.

The county extension agent gets out publicity on such meetings and helps with the overall planning. The soil conservation district supervisors or farmers appointed by them look after many details and arrangements. The soil conservation service technicians supervise the operation of the practices being demonstrated and discuss the technical aspects of the conservation practice.

At large demonstrations or meetings of this type extension specialists in soils and agronomy are in attendance to discuss soils and crop problems. The county extension agent handles such discussion and questions at the smaller meetings. These meetings held right out on the land have been very successful. There is a certain attraction in having equipment in operation and actually doing things. When the crowd is large, a public address system is quite essential.

The chairman of the soil conservation district or the county extension agent usually act as master of ceremonies at such meetings.

In 1945, 14,000 Nebraska farmers attended method demonstrations. The figure for 1946 should be about 20,000.

A large amount of the credit for the conservation work on the land in Nebraska can be given the educational program through method demonstrations, coordinated with on-site assistance.

TOURS

Tours to see soil conservation practices are planned and jointly carried out by the county extension agent, the conservation district supervisors, and the Soil Conservation Service technicians. In counties where the conservation district is new, tours are jointly arranged to nearby counties to see established work. We feel it is quite essential on tours to make stops on farms having complete soil and water conservation programs.

There is no substitute for seeing. Tours are a means of giving farmers an opportunity to see established work.

ANNUAL CONSERVATION MEETINGS

Annual conservation meetings have been held in many Nebraska counties. These meetings are arranged and carried out jointly by the county extension agent, the conservation district supervisors, and the local soil conservationist. The district supervisors make a report on their accomplishments during the year, the district soil conservationist is usually on the program, and extension specialists from the agricultural college are asked to discuss some phase of agronomy or soils. These meetings have been held all day, in the afternoon, or in the evening.

RESULT DEMONSTRATIONS

In our stubble mulch farming program in Nebraska we have felt the need for good demonstrations. Many farmers have been comparing a good job of the conventional method of farming against a poor job of stubble mulch farming. We have county extension agents, the Soil Conservation Service technicians, the research department on this type of work, and the Extension Soil Conservationist all working together to assist interested farmers in setting up this type of demonstration.

CONSERVATION EDUCATION IN SCHOOLS

The Nebraska State Department of Education is very much interested in teaching conservation in the schools. The biggest problem in this endeavor is the training of school teachers along this line. In several counties the county extension agents and the district soil conservationists have worked with the county superintendents in training rural teachers in soil conservation. In one Nebraska county, the chairman of the board of supervisors of the conservation district was very much interested in this work. He asked the county superintendent to get in touch with the county extension agent to work out a program of conservation education in the schools. The county extension agent called in the district soil conservationist and the extension soil conservationist and a very good program of conservation education in the schools has been worked out.

TRAINING SCHOOL

The agronomy department of the Agricultural College of the University of Nebraska has held short training schools twice annually for field technicians of the Soil Conservation Service in Nebraska. These training meetings help to keep the Soil Conservation Service technicians informed of new developments in crops and soils work and keep field recommendations consistent.

ACTIVITIES

Soil Conservation Service field technicians assisted the Extension agronomist this fall in determining yields in the Nebraska Corn Yield Contest. The extension agronomist was desirous of receiving this assistance to facilitate this part of his program and the information gathered will be of use to both the soil conservation program and the extension agronomy programs.

PRESS AND RADIO

The Omaha *World-Herald* "Soil Conservation Recognition Program" is one of the nation's outstanding examples of business becoming interested in an agricultural program.

The pictures and stories on soil conservation which they have brought to the attention of our farmers and ranchers have been a factor in interesting farmers to cooperate with conservation districts and in getting conservation practices on the land.

At the request of the *World-Herald* the details of this program were worked out cooperatively by the Nebraska State Soil Conservation Committee, the Extension Service, the Soil Conservation Service, and the Farm Editor of the *World-Herald*. The carrying out of this program has been handled in the same joint manner on both a state and county level.

Many of our state and county newspapers have put out special conservation editions. The material for such editions has been furnished jointly by the Extension Service and the Soil Conservation Service. The local county extension agents and the soil conservation technicians weekly release result and spot news stories to the local county papers. These are released according to the procedure locally agreed upon. The local people within the county receive much information from the county papers.

LOCAL COMMUNITY MEETINGS

When local community meetings are held, the need for and plans are worked out with the soil conservation district supervisors, the county extension agent, and the Soil Conservation Service technician. The county extension agent is responsible for publicity and invitations to such meetings. The Soil Conservation Service technicians assist with the technical discussion in soil and water conservation.

PUBLICATIONS

We have developed a "Guide to Conservation Farming" for two physiographic areas in Nebraska. This publication was developed by the Extension Service and the Soil Conservation Service with the approval of the State Soil Conservation Committee. It is printed by the Extension Service. To localize this publication, the name of the county and a local picture are used on the cover page for each respective soil conservation district.

The Extension Service and the Soil Conservation Service have developed a circular, "Grass Down Field Waterways". We are in the process of developing a number of soil conservation circulars on this basis.

FARM UNIT PLANNING

The Farm Unit Planning program in Nebraska is carried on where farmers are cooperating with soil conservation districts. The Farm Unit Plan is made after the soil and moisture conservation plan has been made by the soil conservation district. We believe the Farm Unit Planning program will progress satisfactorily under this coordinated arrangement.

To get the job of soil conservation done we must have and must maintain proper relationships between all of the agencies involved. With increased emphasis on soil and moisture conservation assistance, the help the Extension Service will be able to furnish in an educational way will be much needed. In the writer's opinion and from our experience in Nebraska, the educational program is gen-

erally behind the soil conservation district program of on-site assistance. Our job in the educational field of soil conservation merit the best thinking and assistance we can give it.

Methods of Getting the Job Done on Soil Testing[1]

C. M. Linsley[2]

THE testing of soils to encourage and guide farmers in a sound soil improvement program has been a major project in soil extension in Illinois since F. C. Bauer first organized the soil testing project more than 20 years ago. This project was designed to teach farmers to test and map their fields systematically for lime needs through community soil testing meetings. Farmers were given directions for collecting samples from 40-acre fields and were invited to bring these samples to local testing meetings where they tested their own soil and made acidity maps under the direction of the farm adviser. The testing of soils in this project proved to be a very effective method of teaching the principles of soil fertility and of getting intelligent action. The testing of several million acres of farmland over a period of years played an important part in the rapid increase in the use of limestone. Later, when the phosphorus test was developed by R. H. Bray, this test was also included in the project.

However, as the many emergency programs and extension activities began piling up on the farm advisers, they found less and less time to carry on soil testing as an organized project.

The desire to get a much larger acreage tested and to make the potassium test available to a large number of farmers made it necessary to work out some other plan for testing. For several years we attempted to take care of the potassium testing through a University Soil Testing Laboratory, but the first laboratory was inadequately equipped, staffed, and financed, and the plan did not work out satisfactorily.

The possibilities of a county laboratory had been demonstrated several years ago when three two-county laboratories were set up under the Works Progress Administration Research Project. During the year that this project was in operation 200,000 acres were tested and mapped for acidity, phosphorus, and potassium. The first two counties to employ a man to test soils were Christian and Grundy. However, F. H. Shuman, farm adviser of Whiteside County, was the first to set up a well-equipped laboratory and make soil testing a major project. This laboratory started testing in August, 1944, and since that time has tested over 50,000 acres for more than 1,000 farmers. Sixty-two other counties established laboratories during 1945 and 1946.

ORGANIZATION OF COUNTY LABORATORY

The county laboratories have been set up by the farm adviser with the farm bureau underwriting the costs. These laboratories are located in the farm bureau building where the farm adviser also

[1]Contribution from the Extension Department, University of Illinois, Urbana, Ill. Presented as part of the Extension Program at the annual meeting of the Society held in Omaha, Neb., November 21, 1946. Received for publication December 26, 1946.

[2]Extension Specialist in Soils.

has his office. The University soil testing laboratory with a full-time staff and adequate facilities played an important part in establishing the county laboratories. The staff set up the specifications and assisted in planning the arrangement and equipment and trained the technicians.

The cost of setting up the laboratories has varied from about $250 to $600, depending mainly on the carpenter and plumbing work necessary to convert the available room into a laboratory.

A part-time, and in some cases, a full-time laboratory technician is employed to do the testing. Most laboratories have started with a part-time technician. The technician may be an office secretary, a rural youth leader, organization director, a student, or someone, who, because of personal responsibilities, is satisfied with a part-time job. In most cases, the part-time employee has worked out satisfactorily. In other cases, this arrangement has not been successful, either because the technician had a full-time job already or because the pay was not high enough to attract and hold a capable technician.

A number of counties are now employing a full-time man. In some cases, an assistant farm adviser has been employed to direct the laboratory and make the recommendations to the farmer. When a laboratory is ready to start operating, the farm adviser and technician are asked to come into the University laboratory for a two-day training course under A. U. Thor, the laboratory supervisor. After the county laboratory is in operation, Mr. Thor visits the laboratory from time to time to check on the testing technique and to give the technician further training. As a further check on the accuracy of the testing, the technicians are asked to send samples once a month along with the results of their tests to the University laboratory.

METHODS OF COLLECTING SAMPLES

In most counties the farmers collect their own samples. The laboratory furnishes sacks and a diagram and directions for collecting samples from a 40-acre field. A few county laboratories who employ men for the testing, are offering a sampling service in which the entire farm is sampled. An increasing number of counties are offering this service because it seems to be popular with the farmers and because it gives a full-time job to the technician and makes it possible to employ a better trained man.

CHARGES FOR TESTING AND SAMPLING

With the exception of about four counties which offer free service, a charge is made to cover the wages of the technician and the cost of the testing materials. The common rate is 5 cents for acidity, 10 cents for phosphorus, and 20 cents for potassium tests. Where samples are collected by the laboratory, a charge of 10 to 15 cent an acre is made for this sampling service.

GETTING RESULTS AND RECOMMENDATIONS TO FARMER

Two methods of getting results of the tests and the recommendations to the farmer are being tried out. In some counties this is done

by inviting a group of 10 to 20 farmers in to a soil clinic where the results of the tests and the recommendations are discussed. The need of supplying adequate amounts of nitrogen and organic matter through the growing of legumes regularly in the rotation is given special emphasis in these clinics along with the interpretation of the soil test results.

In other counties the individual farmer is invited to come into the farm adviser's office for a discussion of the tests and recommendations.

Cardboard charts in color, mimeographed charts, and other material have been furnished to the farm adviser for use in the clinics as well as in the individual conferences. A series of newspaper mats featuring soil testing and soil treatment have also been prepared for use in the local papers and farm bureau bulletins.

Report forms.—A record of the soil tests along with recommendations for soil treatment is furnished to the farmer either on a report sheet or on map sheets on which the sample locations correspond to those on the diagram used in collecting the samples. Where the report sheet is used, the recommended treatments based on the tests are either written on the report sheet or in an accompanying letter. Where maps are used in reporting the soil tests, three maps are prepared showing, respectively, the results of the acidity, phosphorus, and potash tests. If the tests show areas with important differences in the lime, phosphate, or potash requirements, such areas are outlined and the recommended amounts of the materials needed are written directly on the maps. In some cases, the areas with different requirements are shown in different colors on the maps. The use of the maps seems to be the simplest and most effective method of reporting the results to the farmer and more counties are changing to this method.

Where the entire farm is sampled, the results of the tests are reported on three farm maps which are colored to show the different lime, phosphate, and potash requirements.

The recommended amounts of phosphorus and potash for soils showing the various tests as worked out by R. H. Bray are given in Table 1 and 2.

FOLLOW-UP IMPORTANT

The follow-up is, of course, the important part of the project and at the same time the most difficult. The soil tests, no matter how accurate, are of no value unless the farmer follows through with the recommended treatments. The goal is not the number of acres tested, but the number of acres brought under a balanced program of soil management. Getting the results to the farmer in a way that is understandable and convincing has been one of the problems. Since we have no tests for nitrogen and organic matter, it has also been a problem to devise ways and means of giving this phase of soil improvement equal emphasis with lime, phosphate, and potash. Unless the farmer understands the importance of rotations for both soil

TABLE 1.—*Amounts of phosphate needed.*

Phosphorus tests	Rock phosphate	Superphosphate 0–20–0
	Pounds needed per acre for 8–10 years	Pounds needed per acre in 4-year rotation
Low − (L −)	1,500	500
Low (L)	1,300	450
Low (L+)	1,200	425
Slight − (S −)	1,100	400
Slight (S)	1,000	380
Slight + (S+)	900	370
Medium − (M −)	800	350
	Maintenance	
Medium to high	700	325
High +	None	None

TABLE 2.—*Potash requirements for 4-year rotation.*

Test	Pounds of muriate of potash needed per acre for 4-year rotation	
Pounds of available potassium in an acre of surface soil	0–0–50 (or) 0–0–60	
40	420	350
50	400	330
60	370	310
70	350	290
80	320	265
90	300	250
100	270	225
110	250	210
120	225	185
130	200	165
140	175	145
150	150	125
	Maintenance	
170–200	125	100
200+	None	None

improvement and erosion control and works out and follows an adapted rotation along with any necessary supporting practices for controlling erosion, he falls far short of the goal.

The tests are the basis for the whole soil treatment and conservation program. It is, therefore, highly important that the farmer

understand the recommendations so that he is sure to start and stay on the right road and not allow himself to be led off on some short cut that turns out to be a dead end.

A number of the laboratories are testing 12,000 to 15,000 acres a year, and certainly the larger counties should test that much if we are to make worthwhile headway in a soil improvement program. Working out the recommendations on this acreage and dicussing them with the farmer makes a heavy demand on the time of the already over-loaded farm adviser. Due to the pressure of many other responsibilities there is danger that the important follow-up work will be slighted and many of the possibilities of the testing program may be lost. In addition to the job of getting the farmer to understand the recommendations to the point where he can and will follow them through, there is the equally important job of making the lime, phosphate, and potash conveniently available. The final effectiveness of soil testing in promoting soil improvement will depend on whether farmers are able to obtain the recommended soil treatment materials. Shortages of materials, especially potash, have already been a serious handicap in our testing project.

LASALLE COUNTY PLAN

A plan that we believe will solve some of the problems is now being tried out in LaSalle County. Here an experienced assistant farm adviser has been placed in charge of the laboratory and follow-up work. The plan includes a sampling service, mapping of the farm for lime, phosphate, and potash needs, and a visit to the farm by the assistant farm adviser to discuss the tests and to assist the farmer in working out plans for soil treatment and a suitable rotation. The charge for the sampling testing and follow-up visit to the farm is 35 cents an acre.

SOIL TESTING SAVES COSTLY GUESSWORK

In spite of the difficulties the soil testing project seems to have great possibilities as a means of encouraging and guiding farmers throughout the state in a balanced soil management program. It carries good selling psychology. It has appealed to farmers because they can see where it saves them costly guesswork. Frequently, it will point out to the farmer the cause of crop failures, or low yields because of a failure to use enough plant food material, or it will save them losses in buying the wrong soil treatment material. In some cases, farmers have had one or more carloads of limestone on order and before delivery have found on testing that their soil already had plenty of limestone, but that phosphate was badly needed for clovers as well as other crops. In some cases farmers had ordered a carload of rock phosphate only to find on testing that the phosphorus tests were high but potassium was seriously deficient.

The soil testing project has given an opportunity to correct mistaken ideas regarding the kinds and the amounts of plant food needed for a rotation and the amounts found in different fertilizer materials. Many have the idea that any fertilizer in any amount will give

maximum yields and build up the supply of plant food in the soil. Frequently a farmer will be following the practice of hill-dropping about 125 pounds of 2-12-6 for corn. If he is growing wheat he may drill another 125 pounds with this crop. A test of the soil may show that 300 pounds of 0-0-50 is needed for the rotation or about 10 times the amount of potassium he is supplying in his present fertilizer program. The phosphorus test will often show him that he is supplying about 30% of the phosphorus requirement of the soil.

SOIL TESTING AN EFFECTIVE TEACHING METHOD

Soil testing offers both the farmer and the extension worker a place to take hold of a subject that is difficult for extension to teach and for the farmer to understand and apply. Unless the farmer knows whether or not his soil needs lime, phosphate, or potash, the extension worker's effort at teaching and getting action is limited to general recommendations which cover a variety of soil conditions and which have to be qualified until they lose their meaning.

With a definite knowledge of the soil invoice field by field, the extension worker can get away from useless generalities and get down to the business of making definite recommendations to cover the farmer's specific problems, and, after all, that is what he is interested in doing.

Extension Program on Fertilizers in Iowa[1]

H. B. CHENEY[2]

THE EXTENSION program in Iowa on fertilizers has been developed to meet a recognized need of furnishing the farm people in Iowa with more accurate information on the proper use of fertilizers to fit their particular soil and crop conditions. Moreover, it is firmly based on extensive research results on the major soil areas of the state. It is only when extension programs are developed on the basis of accurate facts to meet the real needs of farm people that they are most successful. These methods and programs must be examined continually if they are to keep pace with our changing agriculture.

In order to understand the methods used and the reason for their adaptation, it is necessary to review briefly the situation in Iowa as regards the need for fertilizers, soil variations, integration of research and extension work in agronomy, status of research information, and farmer interest and knowledge.

HISTORICAL

Fertilizer work, both research and extension, has been conducted for many years in Iowa. As in most new agricultural regions, major emphasis was at first placed on phosphorus rather than on nitrogen and potassium. From 1937 to 1943, considerable emphasis was placed on demonstrating on a farm unit basis the place of high analysis phosphate fertilizers furnished by the Tennessee Valley Authority. At one time, over 300 farmers cooperated on this program in 28 counties. Likewise, considerable field demonstrations were conducted from 1935 to 1942 on fertilizers high in potash for corn on the high-lime areas in north central Iowa. These programs did much to stimulate interest in the use of fertilizers in the state.

Marked changes in the attitude of both farmers and agronomists have occurred in the past 10 years toward the place of fertilizers in farm production and soil conservation. Fertilizer consumption has approximately doubled in the nation since 1935–39. In the corn belt states it has increased over four times. In Iowa the increase has been 18 times. In 1938 fertilizer consumption in Iowa was only 8,000 tons. By 1945, it had increased to over 150,000 tons. Demand still exceeds supply.

Since less than 5% of Iowa farmers were using fertilizer previous to 1940, it is not surprising that their knowledge of fertilizer grades and use was most limited. However, farmers, dealers, and others have been eager and willing to learn whenever opportunities have been offered them to do so.

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Increased emphasis was placed on fertilizers and soil fertility as the war food production programs were initiated in 1942. In recent years much of the soil management extension work has been bulit around fertilizers. This was possible because of the good research information available and the interest in fertilizers on the part of the farmers.

INTEGRATION OF EXTENSION AND RESEARCH PROGRAMS

The fertilizer program at Iowa State College is an integrated program covering both research and extension phases. No extension program can be stronger than the facts on which it is based. Much of the success of the extension fertilizer program in Iowa can be attributed to its close integration with the research program. The need for adequate research background and for close cooperation between research and extension has been recognized and discussed by others. (7, 8, 10).[3]

Research agronomists in soil fertility, with the close cooperation of extension workers since about 1940, have obtained the kind of facts about fertilizers most needed. These included the fertilizer response obtained (a) on different soil areas, (b) on different crops, (c) from all combinations of nitrogen, phosphorus, and potassium, and (d) from different methods of application. Other special problems were also studied. Moreover, the field program has been supplemented with laboratory research that helps to explain many of the results obtained. Special attention was given to the development of chemical soil tests that could be used in making sound fertilizer recommendations. Such tests are now in use in the new soil testing laboratory.

As a result of the field research program and with the help of soil classification co-workers in the Experiment Station, the state has been divided into six major soil areas as related to fertilizer need and response. Fertilizer recommendations are developed for each of the six areas(5). In Fig. 1, the six soil areas are shown as well as fertilizer consumption by counties in 1944. It will be noted that more fertilizer was used in areas 1 and 2 where the need for fertilizer is greatest. Likewise, consumption is lowest in western Iowa in area 6 where there is less need for phosphate-potash fertilizers. This regionalization of fertilizer recommendations has been most useful.

The research and extension workers in soil fertility plan their programs jointly. To a considerable extent there is also an exchange of help in actually conducting the program. For example, the extension agronomists help the research men establish and harvest replicated fertilizer experiments. In turn, research workers may help conduct training meetings for county extension workers.

There is no lag in the utilization of new experimental data in our extension program. We follow the experimental work nearly as closely as the research worker. Similarly, the research worker keeps close to the farmers' problems when it comes to planning new research. Moreover, our extension fertilizer program is developed as an integral part of our entire agronomy extension effort. Since Iowa farmers, at

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[3]Figures in parenthesis refer to "Literature Cited", p. 307.

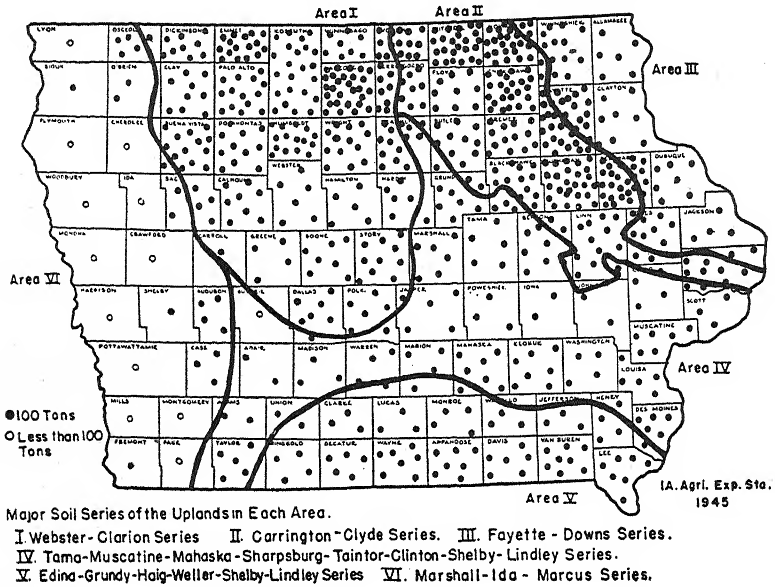

FIG. 1.—Fertilizer use in Iowa, 1944, according to Iowa Yearbook of Agriculture.

the present time, are more interested in fertilizers than in many other phases of agronomy, we use it as a key to drive home the importance of good soil management and conservation.

PHASES OF PROGRAM

It is a well-recognized extension teaching principle that repeated contacts through many media over a period of time are necessary for results. Trotter (12) has shown these principles to apply to agronomy extension work. So in our extension fertilizer work numerous methods and devices have been employed. The methods used are not new or unique. They have been used to a greater or less degree in many states. We have attempted to utilize as effectively as possible those methods that seemed best adapted to supplying our farm people accurate, usable information on fertilizers and their use.

Special emphasis was placed on training leaders and supplying them with aids to conduct the program locally. General meetings, field demonstration plots, 4-H projects, charts, kodachrome slides, movies, news and radio releases, exhibits, and publications were all used. Attention will be directed specifically to the methods used in Iowa during the Extension Service program year, October 1, 1945, to October, 1946. Although this will involve the use of considerable detail, it is hoped that it will also permit a clearer understanding of the actual methods used and how they fit together.

TRAINING COUNTY EXTENSION WORKERS

The training of leaders is considered of first importance in multiply-

ing the efforts of the extension specialist. Gross (6) particularly emphasizes this point. It is considered essential that county extension workers be adequately trained and supplied with useful extension tools that they can use in their own counties. Two such training meetings were held especially for county extension workers during the year. In addition, most of the county workers also attended one or more other meetings on fertilizers conducted by an agronomy specialist.

In November at a state meeting of all county extension directors, one-half day was devoted to soil testing. Both research and extension agronomists participated. The principles of soil testing were reviewed and the results of various tests on Iowa soils summarized. A proposal for a new expanded soil testing program was presented and discussed. This program was later adopted and put into effect. It is fast becoming an integral part of our fertilizer program. Previous to this state meeting, the county extension directors were sent a questionnaire covering the kind and amount of soil testing being done in the counties, the methods being used, and specific suggestions.

A second training meeting was held for county extension workers at nine district conferences in September. Two hours were devoted to the subject of fertilizers and soil testing at each conference program. Our purpose was to train the county workers and, above all, to place in their hands certain extension tools that they could use in the conduct of their program with fertilizers.

The first tool presented was a rather complete discussion outline on fertilizers and soil testing. This outline was intended as a guide to the county extension worker in preparing for talks and publicity on fertilizers. Wherever possible, the discussion outline was implemented in an appendix with tabular experimental results and other tables useful in illustrating the points in the outline. The experimental results were presented in tabular form and then briefly interpreted.

To facilitate further the use of the discussion outline, a set of 44 kodachrome slides was prepared to follow this same outline. Seventy-five sets of these slides were sold to the counties. The average cost to the county was $8.00 per set. Likewise, all of the current pamphlets and mimeographed material on fertilizers and soil testing were bound together with an index, so that the county worker could easily refer to any needed reference. Sixteen items in all were included.

Throughout the discussion with the county extension workers, attention was directed to how they might use this material in their county work. For example, certain parts of the discussion outline were selected that might adequately furnish the basis for short talks on fertilizers at numerous meetings in the county.

TRAINING OTHER LEADERS

In order to train the key people in each county who are making fertilizer recommendations to farmers, 18 district fertilizer meetings were held in January. These meetings were planned primarily for fertilizer dealers and others who make fertilizer recommendations. The county extension director notified the dealers and other leaders

in the county who should attend. Fertilizer dealers, machinery dealers, county extension directors, Soil Conservation Service personnel, vocational agriculture instructors, county AAA committees, and Farm Security workers attended these meetings. Nine hundred twenty leaders attended and participated in the discussion at this series of meetings, Due to the intense interest, 21 similar meetings were planned for December 1946.

Special state or district meetings on fertilizers also were conducted for other groups. At the request of the Soil Conservation Service, extension agronomists met with their personnel in six district meetings in March to review fertilizer recommednations and to outline the new soil testing program initiated in January 1946. During the winter, one representative of the governing body from each of the 62 Soil Conservation Districts attended a training meeting at Iowa State College. As a part of this program, fertilizers and soil testing were discussed. Representatives of the fertilizer manufacturers and distributors doing business in the state met at the college in December to review recent experimental results and discuss fertilizer grade standardization. They also cooperated by encouraging their dealers to attend the district fertilizer meetings. Likewise, the AAA state committee cooperates with the college in developing and carrying our their fertilizer program.

GENERAL MEETINGS

In addition to leader training meetings all of the extension agronomy specialists conducted fertilizer meetings with farmers in most of the counties of the state. Most of these were winter meetings at which charts and kodachrome slides were used. Some were held during the summer on demonstration plots One hundred fifty-seven general meetings, other than the training meetings listed above, were conducted with over 10,000 people attending from 80 counties. County extension workers likewise discussed the subject at many local meetings.

In order to keep our farm leaders informed of the research work in progress on the four agronomy experimental farms, field days were conducted in June and September. These meetings are planned and conducted jointly by research and extension agronomists. All phases of agronomy, including fertilizers, are covered. Thirteen field days were held with over 3,000 people attending.

FIELD DEMONSTRATION PLOTS

Field demonstrations are one of the most effective tools available to the extension worker in conducting a fertilizer program. Over 300 such demonstrations were conducted in 67 counties. Both research plots conducted largely by the research agronomists and simple demonstrations conducted by the extension agronomists were available for demonstrational use. Both types were integrated into the county program by the county extension director. All were conducted in cooperation with farmers.

Replicated research plots were established in half of our counties.

These included 27 experiments on corn, 43 on small grain, and 28 on legumes and grasses. Extension workers, both specialists and county workers, cooperated with the research agronomists in this phase of the program. These plots have had many uses. First, they are the basis for general fertilizer recommendations. They serve as field demonstrations and are an excellent source of result kodachrome pictures. Such plots also help in training county extension workers and a select group of demonstrators. The results furnish the principal basis for the entire fertilizer program. Moreover, these experiments are used to calibrate the chemical soil tests used in the soil testing laboratory.

Simple fertilizer demonstrations were established in 50 counties. Two types have been used. In the one type, the farmer fertilizes his field as usual but leaves one or more areas without fertilizer as a check. In the other type, small plot demonstrations are established comparing the results from different fertilizers selected on the basis of a previous soil test.

Both types of demonstrations were established on Clinton oats. This new disease-resistant, stiff-strawed variety of oats was increased on 500 farms in 1946. Fertilizer demonstrations were established on 104 fields in 37 counties. Farmers were encouraged to leave two check strips in their fields one or more rods in width. These plots were used for observational purposes only. If facilities had been available, yields could have been obtained. Soil samples were taken and tested to help the farmer determine what fertilizer to use to get best results. Generally nitrogen and phosphorus are needed for optimum yields.

Since nitrogen fertilizer has been particularly effective in increasing the yield of oats, a number of simple small plot demonstrations were established on Clinton oats using nitrogen. The extension specialist packaged ammonium nitrate or cyanamid fertilizer and supplied it to the county extension directors for this purpose. Areas of 2 square rods each were top-dressed with the nitrogen fertilizer in April.

Additional demonstrations were established under a 4-H Club fertilizer project. In all cases the boys obtained soil samples from the prospective demonstration area and submitted them to the soil testing laboratory. The fertilizer was packaged and supplied to the boys with a carefully prepared outline as to how the fertilizer should be applied and how the demonstration should be conducted.

For oats and clover, four comparisons were made, namely, no fertilizer, nitrogen, phosphorus, and nitrogen plus phosphorus. Each plot was 15 feet wide and 30 feet long. Sufficient fertilizer was supplied so that duplicate plots could be established for each treatment. Observations were made during the season. They will be continued through next year to study the effect on clover or alfalfa. Fifty-eight boys in 16 counties conducted this project.

The 4-H corn fertilizer project was conducted by 47 boys in 19 counties. The fertilizer supplied each boy was determined from the soil test made on the sample which he submitted. On areas that were adequately supplied with phosphorus and potassium, a plan for demonstrating the effect of additional nitrogen fertilizer on a well-man-

aged and a poorly-managed field was used. On soils needing phosphorus and potassium, four treatments were compared in duplicate, namely, no fertilizer, row fertilizer recommended for the field, 40 pounds of nitrogen per acre, and row fertilizer plus 40 pounds of nitrogen. The fertilizer was applied as an early side-dressing when the corn was 2 to 4 inches tall. Each plot was four rows wide by 10 hills long. These plots were harvested in the fall and the yield results summarized.

AIDS AND MATERIALS

Publications were an effective tool supporting the whole program. Particular attention is called to Extension Pamphlet 112 (5) which summarizes the fertilizer recommendations for field crops in Iowa and outlines briefly recommended practices for the best use of fertilizers. Other publications (1, 2, 3, 4, 9, 11) were also printed and mimeographed for use in the fertilizer program.

Numerous visual aids were used. Thirty charts which were used extensively at meetings were prepared for each extension agronomist. Some color on the charts was found to increase their effectiveness. Kodachrome slides, particularly of results on field demonstrations and experiments, were used extensively at general farmer meetings and fertilizer dealer meetings. Likewise, as mentioned previously, kodachrome slide sets were developed and sold to county extension workers for use in their own county. Movies were used in a limited way. The movie "Soil Management For Northern Iowa" was used in the soil areas to which it was adapted. The film "Putting Plant Food To Work" from the National Fertilizer Association was also used at a limited number of meetings. Additional movies in color that are adapted to local conditions could have been used effectively.

The usual news and radio releases were prepared and distributed to carry on the publicity phases of the program. Exhibits and demonstrations were used only to a limited extent. A soil testing exhibit was prepared and displayed at the National Farm Terrace Contest, the WHO Corn Belt Plowing Contest, and the State Farm Bureau Federation meeting. Over 55,000 people attended these events and an estimated 5,000 viewed the soil testing exhibits and had an opportunity to discuss briefly their fertilizer or soil testing problems with the agronomists in charge. In addition, samples of different grades of fertilizers were displayed at a number of such meetings. Since most farmers in Iowa are not familiar with the different kinds of fertilizers, this attracted considerable attention.

An exhibit also was prepared of representative ears of corn taken from different plots in an experiment to study the relation of stand to fertility level. This exhibit helped to get across the story that the stand must be adjusted to the fertility level and that the highest yield per acre is usually obtained from a medium-sized ear.

SUMMARY

Some of the factors considered in the development of an extension educational program on fertilizers are discussed. The program con-

ducted in Iowa in recent years is considered in some detail. The most important points in the progran are listed below:

1. It was based on meeting an important need of farm people.
2. It was an integrated program which was based on accurate facts supplied by research.
3. Field plots were considered a basic essential. Both replicated research plots and simple demonstration plots were conducted on all of the major soils in the state.
4. Leader training was given increasing attention as an effective way for the agronomy specialists to multiply their efforts. Such training did not stop with a lecture, demonstration, or discussion of the subject matter. It supplied the leader with tools such as outlines and kodachrome slides that he could use in carrying out the program in his own locality.
5. General farmer meetings and tours continued to receive attention. Such contacts along with the conduct of field demonstrations helped to keep the specialist close to the farmer and his problems.
6. Aids and materials such as publications, charts, kodachrome slides, movies, publicity, demonstrations, and exhibits were used.
7. Although just started, soil testing has proved to be a valuable part of the entire fertilizer program.
8. It was a continuous program over a period of years.

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Hybrid Vigor in Upland Cotton[1]

P. H. KIME AND R. H. TILLEY[2]

HYBRID vigor or heterosis is usually most pronounced in crosses between species, but occasionally crosses within the species show very definite increases in growth or yield. Hybrid corn is the most outstanding example of this, and is by far the most important from the economic standpoint. During recent years hybrid vigor has also been reported in crosses between varieties or lines of self-pollinated crops within species. In a few instances definite increases in yield have been recorded in the F_1 and later generations of crosses between sib lines.

Hybrid vigor in cotton has been reported by a number of workers. Most of these investigations were with interspecific hybrids, and marked increases in plant growth were recorded in most instances, especially in the F_1 generation of crosses between American Upland, *Gossypium hirsutum*, and Sea Island and Egyptian cotton, *G. barbadense*.

The effect of crossing within the Upland species of cotton has received very little attention. Breeders have made thousands of such crosses to combine desirable characters. General notes were taken on the F_1, but careful measurements or tests to compare the F_1 with its parents were seldom made, probably because the F_1 populations were usually too small. Large increases in growth do not occur in Upland crosses and increases in other characters, such as yield, are not readily detected by observation.

Since crossing within the species of other crops has given increased yields in the F_1, it is logical to believe that Upland cotton might respond in the same way. An experiment to study the effect of hybridization on the yield and other characters of the F_1 and later generations was begun in 1942.

LITERATURE REVIEW

Balls (1)[3] observed an increase in plant height, time of flowering, length of lint, and size of seed in an Upland-Egyptian cross. He (2) reported an increased number of nodes and greater internodal length. Cook (7) observed an increase in several characters in a cross between Egyptian and Kekchi, a Guatamalian cotton belonging to the Upland species. Jenkins, Hall, and Ware (10) report that hybrid vigor in plant size and other characteristics is very pronounced in crosses between the North and South American types, rather evident in crosses between Upland and Hopi, *G. hopi*, and negligible within the Upland species. Kearney (11) crossed the Holden Upland with Pima Egyptian and found that the F_1 exceeded the greater (Pima) parent in plant axis length, internodal length, leaf length and

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[3]Figures in parenthesis refer to "Literature Cited", p. 317.

width, bract, corolla, and pistil length. Ware (19) also found a marked increase in plant height in the F_1 of a Pima × Upright (Upland) cross. Hybrid vigor in height was due to an increase in the lengths of the internodes and not to additions of nodes. Ware (20) reported an increase in seed weight and lint index, and a lower lint percentage in the F_1 of interspecific crosses. The lower lint percentage was due to larger seed rather than to less lint per seed. Ware (21) working with three interspecific hybrids observed hybrid vigor in height of plant, length of vegetative and fruiting branches, size of leaf, yield of seed cotton, and weight of seed. The increase in vigor of a given character varied in the three crosses.

It has generally been assumed that hybrid vigor does not occur in crosses within cotton species. Cook (7) reported a weakened condition in the F_1 of a cross between Upland and Kekchi. Kearney and Wells (12) found no indication of hybrid vigor in crosses between Egyptian varieties. Ware (19), in genetical studies of several qualitative characters which involved extensive crossing among Upland varieties, did not observe any pronounced increase in vigor in either the F_1 or the F_2. On the other hand, Ramiah (14) crossed different eco-types of *G. arboreum* and reported clear-cut heterosis for all characters studied, the magnitude varying in different hybrids.

The writers found only one reference in which heterosis in Upland cotton is reported. Brown (4) crossed two inbred lines from the Express variety, and in unreplicated tests, found that the F_1 generation produced 36.6% more flowers and 25% more seed cotton than the mean of its parents. The average height of the F_1 was 98.5 cm. The mean height of the parents was 88 cm. Brown states that the inbred lines appeared to decrease in vigor as compared with open-pollinated strains.

Several instances of the occurrence of hybrid vigor in crosses within the species of other self-pollinated crops have been reported during recent years. A few of these references are cited because the results are somewhat similar to those obtained by the writers.

Harrington (8) crossed sister lines of three varieties of wheat. Reliance × Reliance produced definitely higher yields from the F_2 through the F_5 than did the parent variety; Apex × Apex through the F_3 and Marquis × Marquis only in the F_3. Rosenquiest (15) also noted hybrid vigor in wheat. Coffman and Wiebe (5) and Coffman and Davis (6) reported increased vigor in certain oat hybrids. In some cases the vigor was carried over into the F_2 generations. Immer (9), working with six barley hybrids, found that the average of all crosses exceeded the mean of the parents in heads per plant, seed per head, weight per seed, and yield of grain. The average yield of the six crosses exceeded the average of their parents by 24% in the F_2, 13% in the F_3, and 5% in the F_4. Veatch (17) reported hybrid vigor in soybeans as increasing the number of nodes, pods, and seed but having little effect on size. Whaley (22) found that heterosis affects the size of tomato fruit very little. Yield was increased by a greater number of fruits rather than by larger individual fruits.

Cotton is usually cross-pollinated to the extent of 1 to 10%, but where insects, particularly bees, are quite plentiful the amount of crossing is much greater. Ware (18) found less than 1% crossing between adjacent rows at the Scott, Ark., Station, while 40.9% crossing was recorded at Fayetteville, Ark. Scott is in the cotton belt and Fayetteville is outside of the cotton-producing area. Pope, Simpson, and Duncan (13) recorded 27% crossing at Knoxville, Tenn. Brown (4) reported 14.7% crossing between adjacent rows at State College, Miss. Other investigators have reported from 1 to 25% crossing.

EXPERIMENTAL PROCEDURE

Inbred lines selected from the Coker 100, Stoneville, and Deltapine 11A varieties were the parents of the crosses studied. The Coker 100 and Stoneville lines are related. Coker 100 was selected from early stock of Stoneville 3 which was a reselection from Stoneville 2. Stoneville 2B is a reselection from Stoneville 2. Stoneville 4B came from Stoneville 1. Deltapine 11A is of hybrid origin and is not known to be related to the Coker and Stoneville varieties. The parental lines were isolated during the period of 1936 to 1940 and were inbred from two to four generations. The number of generations is indicated by the digits set off by dashes after the variety name, except where otherwise stated. Stoneville 2B was mass in-

bred in 1938 and selections and reselections made in 1939 and 1940. Therefore, 2B-3 had two years of inbreeding and 2B-3-1 three years. Deltapine 11A was mass inbred two years before 11A-5 was selected. All the parent lines were carried on by mass inbreeding from 1941 to 1945. They remained quite uniform and showed no evidence of segregation.

The lines from the Stoneville 2B and 4B varieties were quite different. Lines isolated from Stoneville 2B were rather tall, had medium long internodes and large pointed bolls, while the Stoneville 4B-2-1-1-1 line was a low bushy plant with short internodes, heavy foliage, and large round bolls. Coker 100-1-2 was much taller and had larger bolls than 100-1-1-1. It will be noted that crosses Nos. 1 and 5 are almost the same combination. The Stoneville parent in cross No. 1 is a re-selection from the Stoneville parent in cross No. 5. The Deltapine 11A-5 parent produced tall slender plants having small pointed bolls. Six different combinations of crosses were made as follows:

Cross No. 1 Coker 100-1-1-1 × Stoneville 2B-3-1
Cross No. 2 Deltapine 11A-5 × Stoneville 4B -2-1-1-1
Cross No. 3 Coker 100-1-2 × Stoneville 4B-2-1-1-1
Cross No. 4 Coker 100-1-2 × Stoneville 2B-3-1
Cross No. 5 Coker 100-1-1-1 × Stoneville 2B-3
Cross No. 6 Coker 100-1-1-1 × Stoneville 4B-2-1-1-1

The first crosses were made during the summer of 1942, and yield tests carried on during 1943, 1944, and 1945. Several crosses of each combination were made to obtain sufficient seed for planting the yield test. A few F_1 plants of each combination were grown in the greenhouse during the winter of 1942–43 to produce F_2 seed for planting the test in 1943. The parent plants of the original crosses were transferred from the field to the greenhouse where additional crosses were made and more selfed seed obtained from the parent plants.

The parent plants were taken back to the field in the spring of 1943 and crosses made for the 1944 test. Crosses for the 1945 test were made on the selfed progenies of the original parent plants. Self-pollinated seed from the F_1 generations were used for planting the F_2 the following year, and selfed seed from the F_2 generations were used for planting the F_3 in 1945.

A split-plot experimental design with six plots, four sub-plots, and four replications was used. The two hybrid generations of each cross and their respective parents were kept together in the split-plot for closer comparison. The sub-plots were single rows, 24 feet long, hills 2 feet apart, one plant to the hill, and 12 plants for a perfect stand.

Data were obtained on the following characters during the years indicated:

	1943	1944	1945
1. Yield of seed cotton	x	x	x
2. Yield of lint cotton	x	x	
3. Percentage of lint	x	x	
4. Rate of blooming	x	x	x
5. Earliness of opening	x	x	x
6. Size of bolls	x	x	x
7. Lint index	x		
8. Seed index	x		
9. Height of plants	x	x	x
10. Weight of plants	x	x	x
11. Fiber strength (Pressley)	x		
12. Fiber length (U.H.M.)	x		

Statistical analyses were made, using either the total of the sub-plot or the average of the plants in the sub-plot as the unit. The sub-plot totals were used for yields of seed cotton, lint, flower counts, open boll counts, and weight of plants. Averages of the plants in the sub-plot were used for analysis of other characters.

In calculating significant differences the F_1 and F_2 generations were compared with the greater parent rather than with the means of the parents. Greater differences were therefore required for significance than if the means of the parents had been used.

RESULTS

COMPARISON OF F_1 GENERATIONS WITH THEIR PARENTS AS A MEASURE OF HYBRID VIGOR

Yields of seed cotton.—Higher yields were recorded for each of the F_1 generations than for its most productive parent during all three years. However, the differences were not significant for all crosses during all years. The three-year average yield for each cross showed the F_1 to be highly significant (1% point) over its best parent in five crosses and significant in the other cross. The generation means of the six crosses for the three years show that the F_1 exceeded the most productive parent by more than three times that required for high significance (Fig. 1). Yields of seed cotton are given by years in Table 1. The 1943 yields averaged less than half of that obtained in 1944 and 1945. The 1943 season was dry, cotton made a small growth and opened early. The 1944 and 1945 crops made a normal growth and opened somewhat later. Harvesting was completed by October 15 in 1943 and by November 10 in 1944 and 1945.

TABLE 1.—*Mean yields of seed cotton by years, averages of four replications in grams per plot.*

Cross No.	Generation	1943	1944	1945	Averages
1	F_1	1,075	1,967	1,733	1,592
	F_2	914	1,877	1,746	1,512
	Coker 100–1–1–1	771	1,723	1,553	1,349
	Stoneville 2B–3–1	765	1,680	1,588	1,344
2	F_1	928	2,038	1,841	1,602
	F_2	708	1,642	1,640	1,330
	Stoneville 4B–2–1–1–1	763	1,484	1,586	1,278
	Deltapine 11A–5	623	1,515	1,526	1,221
3	F_1	904	1,957	1,948	1,603
	F_2	808	1,983	1,756	1,516
	Coker 100–1–2	739	1,640	1,842	1,407
	Stoneville 4B–2–1–1–1	733	1,690	1,677	1,367
4	F_1	893	1,638	1,672	1,401
	F_2	786	1,692	1,704	1,394
	Coker 100–1–2	709	1,538	1,646	1,298
	Stoneville 2B–3–1	665	1,455	1,512	1,211
5	F_1	809	1,846	1,728	1,461
	F_2	701	1,635	1,638	1,325
	Coker 100–1–1–1	707	1,632	1,566	1,302
	Stoneville 2B–3–10	728	1,562	1,404	1,231
6	F_1	932	2,036	1,876	1,615
	F_2	984	1,952	1,696	1,544
	Coker 100–1–1–1	745	1,871	1,728	1,448
	Stoneville 4B–2–1–1–1	719	1,758	1,801	1,426
L.S.D. between generations in any one cross:	.05	139	243	171	106
	.01	172	324	228	140

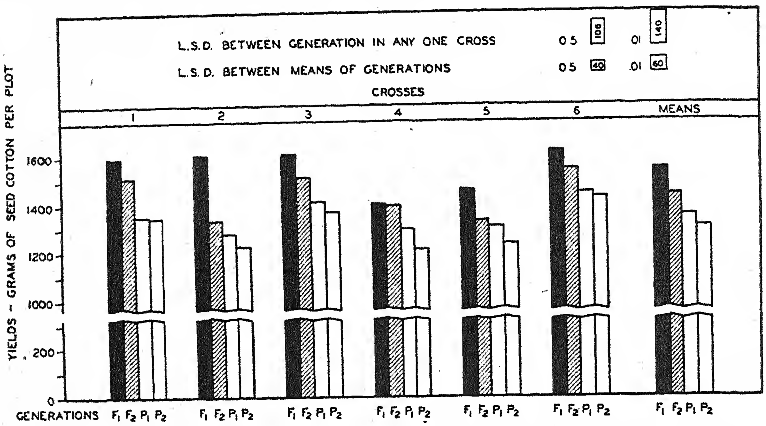

FIG. 1.—Yields of seed cotton from the F_1, F_2, and parents of six crosses, three-year averages.

Yields of lint cotton.—Yields followed much the same trend as seed cotton. Small differences in lint percentages caused minor variations in lint yields, but the relative standing of the hybrid generations to their respective parents remained the same as for seed cotton yields.

Percentage of lint.—Data on this character were obtained in 1943 and 1944. The mean lint percentage of the F_1 generations for the two-year period was slightly below that of the higher parent. Partial dominance was indicated.

Rate of blooming.—Daily bloom counts were made, starting soon after blooming began and continuing for 20 to 25 days. Bloom counts on the F_1 generations were significantly higher than their best parents in 1943 and 1944 and equal to them in 1945 (Table 2). The F_1 was highly significant over the best parent for the three years.

TABLE 2.—*Mean number of blooms per plot.*

Generations	July 18–Aug. 14, 1943	July 11–Aug. 3, 1944	July 17–Aug. 15, 1945	Average
F_1	297	138	297	244
F_2	272	135	285	231
Higher parents	260	122	295	226
Low parents	229	104	255	196
L.S.D.: .05	18	16	32	9
.01	24	21	44	12
Significance between the F_1 and better parent	1%	5%	0	1%

Earliness of opening.—The open bolls were counted a few days before the first picking was made. The F_1 generation mean was significantly greater (1% point) than the better parent in 1943, somewhat higher but not significant in 1944, and equal to the better parent in 1945 (Table 3).

TABLE 3.—*Mean number of open bolls per plot.*

Generations	Sept. 24, 1943	Sept. 20, 1944	Sept. 27, 1945	Average
F_1	72	46	165	94
F_2	58	45	148	84
Higher parents	54	41	163	87
Low parents	42	30	109	60
L.S.D.: .05	8	8	18	10
.01	10	10	24	14
Significance between F_1 and better parent	1%	0	0	0

Size of bolls.—The average weight of seed cotton per boll was used as a measure of boll size. The F_1 was barely significant over the heavier parent in 1943 with no difference in 1944 and 1945.

Lint index (weight of lint from 100 seed).—Data on this character were obtained only on the 1943 crop. The F_1 generation of crosses 1, 3, and 4 had significantly higher lint indices than their highest parents. In the means of generations both the F_1 and F_2 were significant over the higher parent at the 1% level.

Seed index (weight of 100 seed).—Seed weights were obtained on the 1943 crop. The F_1 equalled the heavier parent only in cross No. 1. The means of generations showed the F_1 to be slightly below the higher parent, but above the average of the parents.

Height of plant.—The means of the F_1 generations were approximately intermediate between the parents.

Weight of plants.—After harvesting was completed and all the leaves had shed, the plants on each plot were pulled up and air-dry weights taken. The F_1 was approximately equal to the heavier parent during each of the three years.

Although no measurable differences were found in plant growth, the F_1 hybrids in the 1945 test appeared to be more vigorous than their parents when the plants were 10 to 15 inches tall. In looking down the rows the F_1 plants appeared to be broader and to have thicker foliage. A disinterested person who was not familiar with the layout of the experiment was able to pick the F_1 in each split plot in about 70% of the cases.

Fiber strength.—Pressley strength determinations were made on eight plants from each plot of two replications of the 1944 test. The F_1 generations of all crosses were below the stronger parent. The mean was intermediate between the parents.

Length of fiber.—Differences in staple length of the parents were small in all crosses. Only in cross No. 2 was it greater than 1/32 inch. The F_1 mean was approximately equal to the longer parent.

COMPARISON OF F_2 AND F_3 WITH F_1 TO DETERMINE REDUCTION IN VIGOR AS HOMOZYGOSIS INCREASES

The expression of hybrid vigor becomes progressively less in the

F_2 and later generations. The F_2 is expected to lose 50% of the vigor shown in the F_1, the F_3 75%, and so on. The F_1 and the F_2 generations are compared with the means of their parents (Table 4). It is shown that both the F_1 and F_2 generations are considerably above the parental means in yield, earliness of blooming, earliness of opening, and weight of plants. Differences in lint index were small but highly significant. It is also evident that the F_2 has lost part of the vigor shown in the F_1, approaching the 50% loss expected. Other characters showed slight but not significant increases in the F_1 with the F_2 lagging somewhat behind.

TABLE 4.—*Decrease in vigor in the F_2 as compared to the F_1.*

Plant character	No. years data	Percentage increase over means of parents	
		F_1	F_2
Yield of seed cotton	1943–45	18.8**	9.5**
Early bloom counts	1943–45	17.1**	11.4**
Open boll counts	1943–45	33.9**	19.1*
Weight of plants	1943–45	9.0	7.4
Height of plants, inches	1943–45	2.2	1.3
Weight per boll, grams	1943–45	5.4	2.1
Percentage of lint	1943–44	2.0	2.0
Lint index	1943	5.5**	5.8**
Seed index	1943	3.0	1.6
Fiber strength (Pressley)	1944	0.0	0.0
Fiber length (U. H. M.)	1944	1.2	0.0

*5% point.
**1% point.

The F_3 was grown only in 1945. Hybrid vigor was much less evident in the 1945 crop than during either 1943 or 1944. For this reason, it would be unfair to compare the F_3 data for 1945 with the three-year average for the F_1 and the F_2. Table 5 shows the reduction in vigor in the F_2 and F_3 during 1945.

TABLE 5.—*Decrease in vigor in the F_2 and F_3 as compared with the F_1, 1945 crop.*

Plant character	Percentage increase over the parental means		
	F_1	F_2	F_3
Yield of seed cotton	11.0**	4.8	0.5
Bloom counts	8.0	3.6	0.7
Open bolls	20.4**	8.0	5.8
Weight of plants	4.9	5.4	1.5
Plant height	3.0	1.2	0.6
Boll weight, grams	3.3	1.9	0.7

**1% point.

DISCUSSION

Upland cotton is an allopolyploid species originating from a cross between one of the Asiatic species (N=13) and an American 13–

chromosome species. Cytological studies made by Skovsted (16) indicated this and it was later proved by Beasley (3). The two 52-chromosome species *G. hirsutum* and *G. barbadense* show considerable hybrid vigor as compared with *G. arboreum* and other diploids. It then follows that the hybrid vigor reported in this paper indicates the extent to which the allopolyploid has evolved toward typical diploid behavior.

The difference between the F_1 generation and its most productive or better parent was used as the measure of hybrid vigor. If the mean of the parents was used as a basis for comparison, then part of any increase found in the hybrid generations could be attributed to simple dominance. Certainly an amount equal to the difference between the mean of the parents and the greater parent might be due to dominance.

Hybrid vigor in Upland cotton was found to be more pronounced in characters contributing to yield rather than to increased growth of plant parts. It was quite evident in yields of seed cotton and lint, rate of flowering during the early part of the fruiting period, and in earlier opening of the bolls, but there was no definite increase in growth, size of boll, or other plant characters in the F_1. Total boll counts were not made, but there was evidently a greater number of bolls produced by the F_1 and F_2 since there was no increase in the size of boll. These findings are somewhat similar to the results obtained by Veatch and Whaley. Hybrid vigor shown in lint index was not as pronounced as in yield but was significant.

The size of seed of the F_1 was slightly below that of the better parent in contrast to larger seed obtained from some interspecific crosses.

Height of the F_1 generations of these crosses was found to be intermediate, while hybrid vigor is quite evident in some crosses between species.

A few of the other characters studied showed slight indications of hybrid vigor, but there were no significant differences.

Hybrid vigor was most evident in the 1943 crop and least in 1945. Seasonal conditions were probably responsible for these differences. The 1943 season was dry and plants made a rather small growth. The hybrid generations were perhaps better able to withstand stress conditions.

PRACTICAL APPLICATION

Results obtained from the six crosses show that each of the F_1 generations produced significantly higher yields than its most productive parent even though five of the crosses were between the related Coker 100 and Stoneville lines. Crosses between unrelated lines would be expected to show an even greater amount of hybrid vigor, especially where certain contrasting characters, such as large boll versus prolific small boll types, are brought together. Extensive combining ability tests of the many existing inbred lines might result in the discovery of F_1 combinations having much greater hybrid vigor than is here reported.

Purification can be accomplished more rapidly by inbreeding

than by selection from an open-pollinated seed stock, but there may be some loss in vigor particularly if inbreeding is continued through several generations. Although the yield of an inbred line may not be reduced under a given condition, its range of adaptation both as to location and seasonal conditions may be lowered. On the other hand, the breeder in selecting the most prolific and otherwise desirable plants in an open-pollinated seed stock may be getting a large percentage of plants which are heterozygous for yield factors.

Perhaps a combination of the two methods is desirable. (Inbreeding for two or three years to eliminate the undesirable segregates, then bulking several of the best lines which have similar characteristics, especially as to staple length and quality.) If natural crossing can be increased in this bulked seed stock without introducing foreign pollen, it would appear desirable. Selection from the open-pollinated stock and bulking of the best lines may be practiced from this point on provided undesirable types do not occur.

The production of F_1 cotton seed on a commercial scale by hand pollination methods seems impractical at the present time. Natural crossing offers some possibilities provided a sufficiently high percentage of crossing can be induced. Pope, Simpson, and Duncan planted red leaf and green leaf varieties in adjoining rows. Seed from the green leaf parent was saved and planted the next year. The dilute red hybrid plants were easily recognized, and all the green leaf plants were pulled out. Approximately 27% crossing was found. Ware reported 40.9% crossing at Fayetteville, Ark., as compared to less than 1% at Scott, Ark., the same year. Natural crossing in other parts of the cotton belt range from 1 to 10%. Obviously, if natural crossing is to be made use of, the strains or types to be combined must be grown in an area where a high percentage of crossing usually occurs. It is of interest to note that two of the higher percentages of natural crossing were reported from areas where very little cotton is grown.

SUMMARY

The F_1 generations of all six crosses had higher recorded yields of seed cotton than their most productive parents during all three years, but differences were not significant for all crosses during all years. The means of generations show the F_1 to be highly significant in yield over the F_2 and both parents for the three years. The F_2 was also significantly better than either parent. Yields of lint followed the same pattern as seed cotton.

The hybrid generations showed an increase in the rate of blooming during the early part of the fruiting season in 1943 and 1944, and also began opening earlier than their parents.

The lint indices of both the F_1 and F_2 were significantly higher than for either parent.

No increase in size of seed of the F_1 was evident.

The weight of seed cotton per boll was about equal to the best parent.

Other characters studied showed little if any evidence of hybrid vigor.

The F_2 generations have lost much of the vigor shown in the F_1, while the F_3 showed a still greater reduction.

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Composition and Fertilizer Value of Spent Phosphate Catalysts from the Petroleum Industry: "Solid Phosphoric Acid Catalysts" and Copper Pyrophosphate Catalysts[1]

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IN RECENT years phosphates have assumed considerable prominence as catalysts in the refining of cracked gasoline. Casual study of a descriptive classification of catalysts proposed for use in petroleum refining (3)[3] reveals a rather long list of phosphorus compounds that includes oxides of phosphorus, both P_2O_3 and P_2O_5, phosphorus acid, ortho-, pyro-, and metaphosphates of the alkali and alkaline earth metals, and some phosphides. Although very little data relating to the quantities of phosphorus consumed in catalysts are available (1), it is known that by far the larger part of the phosphorus used in petroleum catalysts goes into "solid phosphoric acid catalyst" (7 to 14). A considerable tonnage of spent catalyst occurs as a refinery waste product that is a potential source of phosphorus for fertilizer use. Spent catalyst of another type, copper pyrophosphate catalyst (15, 16, 17, 18, 20), attracts interest as a possible source of copper for plants growing on copper-deficient soil. Selected samples of the two types of catalysts were analyzed and four of them were tested in plant growth experiments. The results of the study are presented in this paper. As far as the authors are aware, the only published work on the fertilizer value of these materials is an article by Fraps (5) who made tests on spent "solid phosphoric acid catalyst".

MATERIALS AND ANALYTICAL METHODS

The materials consist of seven samples of "solid phosphoric acid catalyst" and four samples of copper pyrophosphate catalyst. Phosphoric acid catalysts No. 2386 to 2388 and copper pyrophosphate catalysts No. 2414, 2416, and 2417 were received in 1945, whereas the other samples, Nos. 2382 to 2385, were collected in 1941. Other pertinent descriptive data are presented with the chemical analyses in Table 1.

The materials (20-mesh) were analyzed with the use of standard procedures

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[3]Numbers in parenthesis refer to "Literature Cited", p. 325.

and suitable precautions to insure complete solution of the constituent sought. Phosphorus, both total and citrate-insoluble, was determined on a solution prepared by igniting the sample or residue with magnesium nitrate, since it was found, as was also observed by Fraps (5), that treatment with aqua regia in the customary manner does not bring all the phosphorus into solution. Calcium, alumina, and silica were determined on the solution obtained by fusing the sample with sodium carbonate and dissolving the fusion in hydrochloric acid. Nitrogen was determined by the official Kjeldahl method for total nitrogen including nitrates (2). Copper was determined by electrolytic deposition from a solution obtained by decomposing the sample with sulfuric and hydrofluoric acids. In the extraction of the sample incident to determining citrate-insoluble phosphorus, the water extracts (usually clear) were prepared by washing the sample on Whatman filter paper No. 5, whereas Whatman filter paper No. 41 was used for filtering the citrate extracts.

COMPOSITION OF CATALYSTS

Chemical analyses of the catalyst samples are given in Table 1 and the solubility of the copper of pyrophosphate catalysts is shown in Table 2. The amounts of fluorine found were less than 0.01%. The figures for silica in phosphoric acid catalysts are somewhat lower than those given by Fraps (5); otherwise the two sets of data are in fair agreement. It is a matter of some surprise that these materials show nearly complete phosphorus availability by the official method, whereby the material is washed with water and then digested with neutral ammonium citrate solution, while treatment with strong mineral acid results in very incomplete solution of the phosphorus. The rather high figures for water-soluble phosphorus indicate the large loss of phosphorus that may occur in the event spent catalysts are exposed to the weather. Unweathered phosphoric acid catalysts are very hygroscopic. For example, equilibrium water absorptions by the method of Yee and Davis (21) at 30°C on catalyst No. 2386 were 21.2% and 29.0% at relative humidities of 59% and 65%, respectively. X-ray diffraction photographs of two of the samples (No. 2386 and 2387) showed that the phosphoric acid catalysts are crystalline, at least in part.

CONDITIONS OF GREENHOUSE EXPERIMENTS WITH PHOSPHORIC ACID CATALYSTS

Spring wheat (Pilot variety) was grown in the greenhouse in 8.5-inch glazed earthenware pots containing 21 pounds of air-dry soil (14-mesh). The soil was an Evesboro loamy sand, the optimum moisture content of which was found to be 12% of the dry weight of soil. The experiment, comprising five phosphorus sources and six rates of application, was designed as a factorial with four replicates, and the pots were rotated within their respective blocks in order to minimize growth variations arising from positional effects.

Each pot received an application of 7.46 grams of calcium hydroxide (equivalent to 2,250 pounds of calcium carbonate per acre). The lime was mixed with all the soil 50 days prior to planting, and during the interim the soil was alternately watered to the optimum moisture content and dried three times.

The pots were given a basal treatment of potash and nitrogen 32 days before planting. The soil was removed from the pots and well

TABLE 1.—*Composition of phosphate catalysts.*

No.	Description of sample: Type of material	Percentage P_2O_5: Water-soluble*	Percentage P_2O_5: Available*	Percentage P_2O_5: Total	Total percentage of: CaO (Cu)	Total percentage of: SiO_2	Total percentage of: Total N	Total percentage of: R_2O_3 (Carbon)	Loss in weight at: 105° C	Loss in weight at: 200° C	Loss in weight at: 400° C	Loss in weight at: Total loss
	Phosphoric Acid Catalysts											
2409	Unused material, white	36.3	99.9	63.91	—	—	—	—	0.00	2.92	3.50	6.27
2386	Spent material, white	41.2	99.9	61.50	<1	25.51	0.02	2.04	1.00	2.06	3.65	6.71
2387	Spent material, dark gray	20.4	99.4	59.68	<1	25.54	0.17	1.89	2.10	2.06	3.98	8.14
2383	Spent material, black	54.1	98.6	49.76	<1	25.55	—	1.29	11.60	5.50	2.30	19.40
2385	Spent material, black	35.8	97.8	47.78	<0.1	19.77	—	0.58	4.66	1.63	11.67	17.96
2384	Spent material, black	34.8	97.4	46.42	<0.1	19.12	—	0.70	4.41	1.53	9.19	15.13
2388	Spent material, black	66.0	96.4	24.17	<1	35.06	0.18	0.68	8.85	2.51	7.95	19.31
	Copper Pyrophosphate Catalysts											
2417	Unused material, black	17.6	99.8	28.32	(24.10)	—	—	(26.9)	4.07	0.79	2.80	7.66
2414	Spent material, black	20.7	99.8	37.88	(16.90)	—	—	(28.1)	14.32	4.60	10.13	29.05
2382	Spent material, black	21.8	87.3	17.64	(17.60)	0.18	—	—	2.04	2.49	21.84	26.37
2416	Spent material, black	11.6	87.7	12.95	(16.72)	—	—	—	7.64	—	33.30	40.94

*Percentage of total P_2O_5.
†Calculated from weight of ammonia precipitate by considering it to be $AlPO_4$.

TABLE 2.—*"Solubility" of copper pyrophosphate catalysts by extraction with water and neutral ammonium citrate in accordance with official method for available phosphates.*

Description of sample		Cu		
No.	Type of material	Total, %	Water-soluble, % of total	Water- and citrate-soluble, % of total
2417	Unused material, black	24.10	8.7	>99.0
2414	Spent material, black	16.90	8.3	58.5
2382	Spent material, black	17.60	6.8	71.6
2416	Spent material, black	16.72	<0.1	55.1

pulverized before adding the fertilizer, which was mixed with all the soil. Potash was applied as potassium sulfate (54.06% K_2O) at the rate of 150 pounds of K_2O per acre; nitrogen at the rate of 75 pounds per acre with equal quantities from ammonium sulfate (21.20% N) and sodium nitrate (16.48%). A second application of nitrogen (in solution) with the use of the same materials and rate was made 38 days after emergence of the plants.

Minor elements were applied in the form of a solution 17 days prior to planting. The elements and their amounts in parts per million of soil were B, 1; Cu, 0.5; Zn, 0.1; Mn, 0.1; Fe, 0.5,; and Mg, 10.

The phosphorus carriers were applied in the top 3-inch layer of soil 18 days prior to planting by removing 8.75 pounds of soil from the pot, pulverizing it, and then mixing in the fertilizer. The application of phosphoric acid to the checks was made by diluting a weighed quantity of 85% phosphoric acid to 25 cc, mixing the resulting solution with 2 pounds of soil, and then incorporating this mixture with the remainder of the soil from the top 3-inch layer. The soil acidities found at the end of the growth period for two series of treatments are given in Table 3.

TABLE 3.—*Soil pH values at end of growth period.**

Application of P_2O_5 per acre, pounds	pH when phosphorus carrier was	
	Spent phosphoric acid catalyst No. 2386	Phosphoric acid
0	5.7	5.7
50	6.0	6.2
100	6.0	6.2
250	5.7	5.8
500	5.7	5.8
1,000	5.4	5.5
2,000	5.0	4.3

*Soil samples from the replicates of each treatment were composited and thoroughly mixed for the pH determination.

The wheat (89% germination) was planted December 7, 1945, at the rate of 32 seeds per pot with subsequent thinning to 15 plants on

December 17 and finally to 12 plants on December 21. Plants that appeared to have least vigor were removed in the last thinning. The over-all stand was 83% on the fourth day and 85% on the fifth day after planting. Phosphoric acid treatment at the 2,000-pound rate was definitely harmful as regards both the number of plants emerging and the time required for emergence. The plants were harvested just prior to the boot stage on February 27 after a growth period of 79 days.

FERTILIZER VALUE OF PHOSPHORIC ACID CATALYSTS

In the greenhouse experiment the growth response of spring wheat (Table 4) to phosphoric acid catalysts was nearly as good as that to double superphosphate, which is in agreement with Frap's finding (5). The trend of the results (Table 5) is definitely negative, although the differences attain statistical significance only four times

TABLE 4.—*Yields of wheat on soil treated with phosphoric acid catalysts, phosphoric acid, and double superphosphate.**

Phosphorus carrier	Average dry weight of plants† in grams per pot at P_2O_5 applications in pounds per acre of					
	50	100	250	500	1,000	2,000
Double superphosphate	11.7	20.9	27.2	26.3	28.6	31.3
Spent catalyst No. 2386	9.4	18.3	23.2	29.0	26.7	30.0
Spent catalyst No. 2388	12.9	20.7	19.9	22.9	25.1	23.5
Fresh catalyst No. 2409	7.9	14.7	22.0	24.6	26.2	30.5
Phosphoric acid	12.5	20.0	24.9	28.4	31.6	12.7

*Average dry weight of plants without applied phosphorus was 5.4 grams per pot.
†Differences in average dry weights required for significance are 4.3 at 5% level and 5.7 at 1% level.

TABLE 5.—*Increase in growth response of wheat on soil treated with phosphoric acid catalysts in comparison with double superphosphate and phosphoric acid.*

Phosphorus carrier	Increase† in average dry weight in grams per pot at P_2O_5 application in pounds per acre of					
	50	100	250	500	1,000	2,000
	Compared with Double Superphosphate					
Spent catalyst No. 2386	−2.3	−2.9	−4.0	+2.7	−3.5	−1.3
Spent catalyst No. 2388	+1.2	−0.2	−7.3**	−3.4	−3.5	−7.8**
Fresh catalyst No. 2409	−3.8	−6.2**	−5.2*	−1.7	−2.2	−0.8
	Compared with Phosphoric Acid					
Spent catalyst No. 2386	−3.1	−1.7	−1.7	+0.6	−4.9*	+17.3**
Spent catalyst No. 2388	+0.4	+0.7	−5.0*	−5.5*	−6.5**	+10.8**
Fresh catalyst No. 2409	−4.6*	−5.3*	−2.9	−3.8	−5.4*	+17.8**

†Plus sign indicates that catalyst gave larger yield.
*Significant at 5% level.
**Significant at 1% level.

in 18 treatments. The same trend is somewhat more pronounced in the comparison with phosphoric acid (Table 5), provided that the results at the highest application be disregarded in view of the low pH in the pots treated with phosphoric acid at this rate (Table 3). Spent catalysts were slightly more effective than fresh catalyst.

CONDITIONS OF GREENHOUSE EXPERIMENT WITH COPPER PYROPHOSPHATE CATALYST

Winter oats was grown in the greenhouse in 5⅛-inch glazed earthenware pots containing 1 pound of moist soil. The soil was Florida saw grass peat which has been found to be deficient in copper and to require liberal applications of copper sulfate for normal growth of field crops. The peat was shipped in paper sealed baskets and was received in a moist condition. It was very black, had a pH of 4.85, and contained some undecomposed saw grass. The saturated peat contained about 75% water. The copper content of the air-dried soil was 5.2 ppm. The experiment was designed to test crop response to copper sulfate and to one spent copper pyrophosphate catalyst (No. 2414). Each treatment was run in triplicate. The fertilizer value of the phosphorus in copper pyrophosphate catalysts, which the solubility data (Table 1) indicate to be of a high order, was not determined by growth tests.

The pots were given a basal treatment of calcium carbonate, applied at the rate of 2,000 pounds per acre, and a nitrogen-free fertilizer containing 50 parts of 20% superphosphate, 40 parts of potassium chloride and potassium sulfate (4:1), 5 parts of magnesium sulfate heptahydrate, 1 part of manganese sulfate pentahydrate, 0.1 part of borax, and 0.2 part of zinc sulfate monohydrate, which was applied at the rate of 1,000 pounds per acre. Copper sulfate was applied at the rate of 100 pounds of the pentahydrate per acre and spent catalyst at an equivalent rate.

Winter oats was planted December 13, 1945, at the rate of 12 seeds per pot and subsequently thinned to six plants. The plants were harvested on February 19, 1946, 68 days after planting, by cutting as near to the surface of the soil as possible and at the same time avoid contamination.

In another set of tests (not replicated) winter oats was planted December 13, 1945, in 7-inch baked clay pots at the rate of 15 seeds per pot, later thinned to eight plants and allowed to mature. The grain was harvested June 6, 1946, threshed, weighed, and analyzed for copper.

In a third series of test (not replicated) planted on the same date, shallu was grown in 1-gallon pots containing 4 pounds of soil. The shallu was planted at the rate of 16 seeds per pot and thinned to four plants. It was harvested on February 19, 1946. According to Dr. R. V. Allison, who furnished the soil, shallu shows copper deficiency markedly.

The copper determinations on the plant material were made in accordance with the dithizone method described by Holmes (6) for soils.

COPPER PYROPHOSPHATE CATALYST AS A SOURCE OF COPPER FOR GROWING PLANTS

In the greenhouse experiment the growth response of shallu and winter oats (Table 6) to spent copper pyrophosphate catalyst on copper-deficient soil was as good as that to copper sulfate. Furthermore, the uptake of copper was the same order of magnitude for the two copper carriers. The results indicate that the spent catalyst is equally as good as copper sulfate as a source of copper for growing plants. No toxic effects of the catalyst were observed.

TABLE 6.—*Yields of winter oats and shallu on soil treated with spent copper pyrophosphate catalyst and copper sulfate.*

Treatment	Average dry weight of crop, grams per pot*	Cu content of crop, ppm*
	Immature Winter Oats	
Basal	2.37	2.3
Basal + $CuSO_4$	2.14	5.3
Basal + catalyst	2.24	5.0
	Grain from Mature Winter Oats	
Basal	4.00	2.6
Basal + $CuSO_4$	2.97	3.5
Basal + catalyst	3.80	4.8
	Shallu	
Basal	1.33	1.4
Basal + $CuSO_4$	4.89	5.4
Basal + catalyst	5.48	5.0

*Without basal treatment the average dry weights of immature winter oats without applied copper, with $CuSO_4$ and with catalyst, respectively, were 1.64, 1.69, and 1.71 grams per pot. The corresponding copper contents of the plants were 1.4, 6.2, and 5.5 ppm.

Piper (19) found that the copper content of healthy oat plants decreases with growth progress, and he reported 4.8 to 6.7 ppm of copper in plants 70 days after planting. Drosdoff (4) obtained an average of 2.6 ppm in copper-deficient tung leaves and 5.7 ppm in normal leaves. In cases of copper deficiency, severe enough to cause oat plants to die at an early stage of growth, Piper (19) found the copper content of the plant tops to be 1.8 ppm. Noteworthy in this connection is the authors' observation that after the harvest shallu plants in the copper-treated pots sprouted again, whereas those in the untreated pots died.

SUMMARY

Seven "solid phosphoric acid catalysts" and four copper pyrophosphate catalysts, including both spent and unused materials from the petroleum industry, were subjected to chemical analysis, and their fertilizer value was determined by solubility and plant-growth tests.

"Solid phosphoric acid catalyst" is essentially a crystalline complex of phosphoric oxide and silica. The materials contain, in addition

to silica, 24% to 64% of P_2O_5, 6% to 19% of water, and 0.2% to 2% of R_2O_3. Solubility tests indicated that practically all the phosphorus should be available to growing plants, and this condition was confirmed by the growth response of spring wheat to three of the catalyst samples in greenhouse tests, in which the catalysts were only slightly less effective than double superphosphate on limed Evesboro loamy sand soil. The high observed values for water-soluble phosphorus, being one-fifth to two-thirds of the total and consisting of free phosphoric acid, accounts for the hygroscopicity of the material and indicates the large loss of phosphorus that may occur in the event the spent catalyst stock pile is exposed to the weather.

The copper pyrophosphate catalysts contained 12% to 38% of P_2O_5, 17% to 24% of copper, and were essentially copper pyrophosphate suspended on charcoal. More than 85% of the phosphorus and 55% to 99% of the copper were soluble in the official solubility test for available phosphates in fertilizers. In greenhouse experiments with winter oats and shallu the spent catalyst was found to be a good source of copper for plants growing on copper-deficient soil.

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Sugar and Nitrogen Changes in Topped Sugar Beets Exposed to Very High Temperatures Prevailing at Harvest[1]

J. M. FIFE AND CHARLES PRICE[2]

IN THE Imperial Valley of California sugar beets are planted in the fall, mainly in October, and harvested in May, June, and July of the following year. This reversal of the more general practice of planting beets in the spring and harvesting in the fall came about because the extreme heat of summer there is unfavorable for beets. The fall and early spring there are conducive to good growth and the short winters are mild. The practice is made feasible by the use of a nonbolting variety (U. S. 15) that will not go to seed under those conditions and is moderately resistant to curly top. A nonbolting variety higher in curly-top resistance would be better adapted, at least in the occasional season of relatively severe curly-top epidemics.

Harvest problems in the Imperial Valley are complicated by the very high temperatures that occur with increasing frequency and severity as the season advances. During July, the air temperature (standard shade) may rise to 75° F by 7 a. m. and to 120° F by 3 p. m. Rapid deterioration of harvested and exposed beets is one of the problems that results. Beets exposed on the ground to the sun wither and quickly burn to the extent that they turn dark and begin to decompose. Even with less serious injury, the rate of repiration is so increased that loss of sucrose is accelerated. During the periods of very high temperature, the humidity is low and consequently the beets wilt and become poor in milling quality.

It was shown previously[3] that the practice of severing the roots from the soil several days in advance of topping resulted in a loss of sucrose. There was also an increase in the nitrogen fraction designated in sugar technology as "harmful" nitrogen because of its interference with crystallization of sucrose. These tests were conducted in areas in which the temperatures are much lower than in the Imperial Valley, and the roots were not removed from the soil, so that they were protected from the direct rays of the sun.

Experiments also conducted previously[4] in connection with the chemical changes occurring in sugar beets as a result of different harvesting practices in the Imperial Valley showed that beets topped in place in the soil but not lifted had not changed significantly in dry

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[2]Biochemist and Agronomist, respectively.

[3]PRICE, CHARLES, FIFE, JAMES M., GILLESPIE, GLENN E., and FERGUSON, WILLIAM C. Sucrose loss and changes of nitrogen constituents in sugar beets under conditions of delayed topping. Jour. Amer. Soc. Agron., 33:901–907. 1941.

[4]PRICE, CHARLES, and FIFE, JAMES M. Effect of delayed lifting after topping on certain chemical constituents of sugar beets. Proc. Amer. Soc. Sugar Beet Technologists. 1946.

matter, harmful nitrogen, sucrose, or reducing sugars at the end of 3 days. If the beets were lifted after topping, however, significant changes occurred.

Studies on some phases of the harvest problem in Imperial Valley were conducted in the seasons of 1944 and 1945. They were planned to study changes in topped beets exposed on the ground to the conditions prevailing during the harvest, with special attention given to harmful nitrogen, sugars, and moisture contents.

MATERIAL AND METHODS

In 1944, a field of sugar beets of the variety U. S. 15 growing under favorable conditions near Brawley, Calif., was chosen for these studies. Two rows each 300 feet long of uniformly spaced beets were topped, lifted, and placed on the surface of the soil. Four hundred beets, of a high degree of uniformity in shape, were taken at random for the test. Three hundred and twenty of these beets were placed in ¼-inch mesh onion bags with 10 beets in each bag. The control consisted of the remaining 80 beets. They were placed in water-proof canvas bags and transported the same day to Riverside, Calif. The onion bags containing the beets were spread out on the ground in the direct sunlight with a small space left between each bag for air circulation. At 2-day intervals for the following 8 days, eight onion bags were taken at random for chemical analysis,.

At the laboratory the beets were topped at the lowest leaf scars and brushed free of soil particles. They were then divided into four samples each containing 20 beets of approximately the same size range. A pulp sample was taken from each root by passing it through a rasping machine, which removed a sector extending to the central axis and the full length of the root. The composite pulp sample thus obtained from each 20-beet sample was then thoroughly mixed by an electrically operated mixer and placed in a freezing unit maintained at approximately $-30°$ F until frozen. The frozen pulp was stored at approximately $-5°$ until analyzed.

For the 1945 test, two rows containing approximately 4,000 beets of U. S. 15 were selected from a uniform field of relatively high fertility near Brawley, Calif. The beets were lifted, topped immediately at the lowest leaf scars, and 2,000 of the most uniforn selected for the test. The beets were then laid out in rows on a tan-colored canvas in direct sunlight. Daily maximum temperatures were taken in shade at the ground surface. A sample of 200 beets was taken at random immediately, placed in tight canvas bags and shipped to Riverside for analysis. Similar samples were handled in the same way at daily intervals for the next 5 days.

At Riverside, the 200 beets were arranged according to size and then divided into 10 lots so that each lot contained beets of about the same size range. A one-eighth longitudinal segment of each beet of the ten 20-beet samples was taken by means of a band saw and then pulped by means of a multiple saw pulping machine. The combined pulp from the 20 beets was thoroughly mixed by an electrically operated mixer and about 500 grams removed for chemical analysis. The samples were immediately frozen in a quick-freeze unit and kept frozen until analyzed.

To eliminate so far as possible analytical errors due to differences in the amount of dry matter in the samples taken from fresh and flaccid beets, all samples of pulp taken from beets exposed to high temperatures were adjusted to approximately the dry matter content of the samples taken from the fresh beets (the controls). Pulp samples removed from the freezing units were thawed by immersing the containers in warm water. The entire contents of the containers were removed, weighed, and after the addition of a measured quantity of water (to adjust the pulp to the dry matter content of the control fresh beets) the pulp was thoroughly mixed by means of an electrically operated mixer and the samples weighed out. The dry matter content of each sample was determined accurately after the addition of water. The values were calculated on the dry-weight basis or on a uniform fresh-weight basis (25% dry matter).

The methods used for the determination of harmful nitrogen are essentially those developed by the European investigators. The term harmful nitrogen is here applied to the nitrogen not precipitated by copper hydroxide minus the total

ammonia nitrogen (ammonia plus amids). The methods are as follows: 350 ml of water are added to 100 grams of pulp in a calibrated wide-mouth Erlenmeyer flask and placed in a water bath at 85° C. After the sample has reached this temperature, 50 ml of copper sulfate solution (60 grams of copper sulfate made up to 1,000 ml with water) and 50 ml of sodium hydroxide solution (0.3125 N) are added and thoroughly mixed. The samples are allowed to digest for 15 minutes with frequent shaking, after which they are cooled to room temperature, the air expelled, made up to 500 ml, and filtered clear through dry paper pulp. A 50-ml aliquot is removed from the filtrate for the determination of the nitrogen not precipitated by the copper hydroxide. Nitrogen was determined by an official method[5] which does not include the nitrates. A 125-ml aliquot was also removed for the determination of ammonia plus amid nitrogen. These samples were made 1 normal with sulfuric acid and hydrolized for 2 hours, cooled, then neutralized with sodium hydroxide. The samples were then made alkaline with 40 ml of an alkaline borate mixture (0.5 normal sodium hydroxide in 5% borax) and the ammonia distilled off at atmospheric pressure.

The total soluble nitrogen content of the pulp was determined by placing 10 grams of pulp in a 100-ml Kohlrausch flask with 75 ml of water. This mixture was placed in a water bath at 90° C. Sufficient 1-normal acetic acid was added to bring the pH to 4.7. The flasks with contents were then cooled to room temperature, the air was expelled, the volume made up to mark, and filtration carried out by means of dry paper pulp. Nitrogen was determined on an aliquot of the clear filtrate by an official method which did not include the nitrates.

Determination of sucrose was by the cold water digestion method of Krueger, as modified by Sachs and LeDocte, using 26 grams of pulp.

Reducing sugars were determined on 10 grams of pulp placed in a 100-ml Kohlrausch flask and sufficient neutral lead acetate was added to clear the extract before the volume was made up to mark. The filtered extract was deleaded with sodium oxalate and again filtered. Reducing sugars were determined on a 50-ml aliquot of the lead-free filtrate by the Munson-Walker method[6]. Raffinose was determined by an official method[7] for beet products, using hydrochloric acid to invert the sugars before taking the second polariscope reading.

EXPERIMENTAL RESULTS

Air temperature reached the maximum at approximately 3 p. m. during the sampling period in 1945. The air maximum temperature in shade at the ground surface varied from 114° to 120°F. Beets subjected to these high temperatures gradually turned dark in color and showed some rot at the end of the 6 days of exposure (Fig. 1). The percentage moisture of the roots decreased at a mean constant rate of 3.28 and 2.06% per day in 1944 and 1945, respectively.

Harmful and soluble nitrogen changes are shown in Fig. 2 and Table 1. In the 1945 test the harmful nitrogen was significantly higher at the end of the second day of exposure and throughout the rest of the test. These results are highly reliable because there were 10 replications for each sampling period. In 1944 there were only four replications for each sampling period. This number was not sufficiently large to show statistically significant differences. The observed changes in harmful nitrogen were closely similar for the two years. The increase in soluble nitrogen at the end of the third day of exposure was statistically significant. There was a marked increase in the ratio of harmful nitrogen to soluble nitrogen during the first two days of drying but after this the ratio was lower. This change

[5]Association of Official Agricultural Chemists. Official and Tentative Methods of Analysis. Washington, D. C. 1924.

[6]See footnote 5.

[7]See footnote 5.

FIG. 1.—*At left,* sugar beet exposed on the ground to full sunlight for 6 days during harvest in the Imperial Valley. Rot has set in. *At right,* sugar beet from same original lot as the other kept in a cool refrigerator for 6 days. The sugar beets were approximately the same size at the outset of the experiment.

in the ratio may indicate that the compounds being made soluble during the early and the latter parts of the drying period were different.

Changes in sugars (sucrose, reducing sugars, and raffinose) during the drying period are shown in Fig. 3. Each point on the curves represents the mean values of 4 and 10 replications, respectively, for the years 1944 and 1945. The period during which no significant changes in the percentage of sugars occurred is shown by the broken

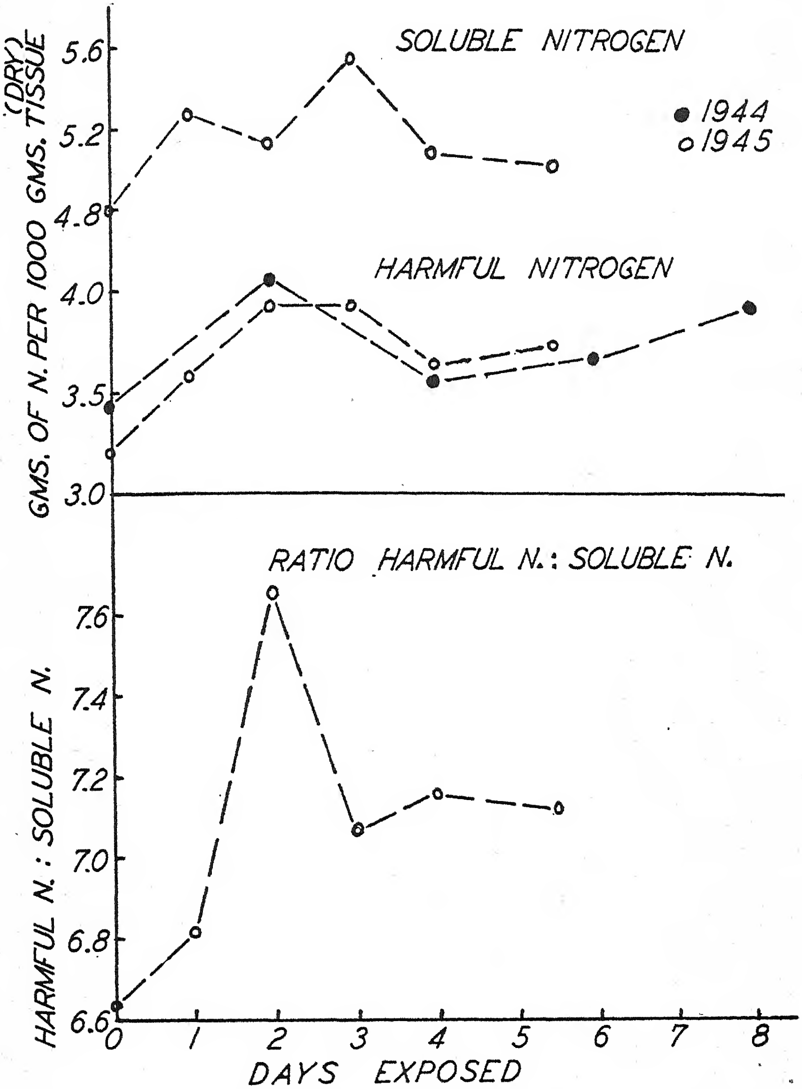

FIG. 2.—Changes in soluble and harmful nitrogen occurring in topped sugar beets exposed to the prevailing conditions at harvest in the Imperial Valley.

line of each curve. The solid lines of each curve (regression lines) show the period in which the changes in the percentage of sugars took place at a constant rate.

The regression of percentage of sucrose in the sugar beets on the length of exposure (as shown by the solid lines) shows that the rate of loss in sucrose was linear for both years. The correlation coefficient exceeded the 5% level for both years. The loss in sucrose was 0.239%

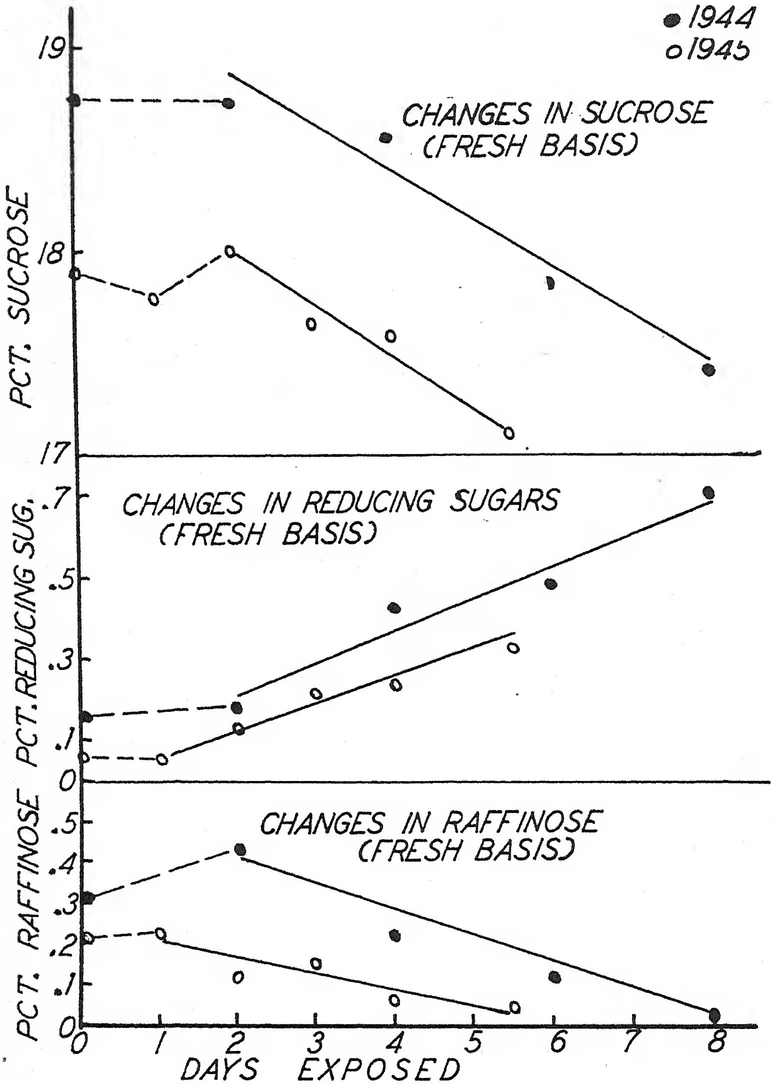

FIG. 3.—Changes in sugars during the exposure of sugar beets to Imperial Valley conditions for varying lengths of time.

and 0.240% per day (fresh basis, 25.0% dry matter) for 1944 and 1945, respectively.

The rate of increase in reducing sugars was linear after the first day of drying until the end of the tests. The correlation coefficient exceeded the 5% level in 1944 and exceeded the 1% level in 1945. The rate of increase in reducing sugars was 0.080% and 0.064% per day for 1944 and 1945, respectively.

TABLE 1.—*Changes in harmful and soluble nitrogen and sugars in sugar beets exposed to Imperial Valley conditions for varying lengths of time during the harvest period.*

No. of days xposed	Nitrogen*		Sugars†		
	Harmful, grams	Soluble, grams	Sucrose, %	Reducing, %	Raffinose, %
			1944‡		
0	3.427	—	18.77	0.17	0.31
2	4.045	—	18.75	0.18	0.43
4	3.559	—	18.55	0.43	0.22
6	3.669	—	17.82	0.48	0.12
8	3.931	—	17.40	0.70	0.00
			1945§		
0	3.183	4.805	17.90	0.05	0.20
1	3.586	5.267	17.78	0.06	0.22
2	3.914	5.118	18.00	0.12	0.12
3	3.913	5.542	17.65	0.20	0.15
4	3.682	5.071	17.59	0.23	0.06
5.5	3.725	5.229	17.11	0.33	0.04

*Grams of nitrogen per 1,000 grams of dry tissue.
†Fresh weight basis (calculated to 25% dry matter).
‡Beets exposed on the ground in ½-inch mesh onion bags. Values are the mean of four replications.
§Beets exposed on the ground on a tan-colored canvas. Values are the mean of 10 replications.

The rate of decrease in the percentage of raffinose was constant after the first day. The correlation coefficient exceeded the 5% level for both years. The rate of decrease in the percentage of raffinose was 0.070% and 0.038% per day on the fresh basis.

The rate of loss in sucrose approximated 4.8 pounds per ton of fresh beets for each day the beets were exposed. This loss was probably due mainly to inversion. The calculated losses in total sugars in 1944 and 1945 were approximately 9% and 4%, respectively, at the end of the periods of exposure. These losses were probably due mainly to respiration.

SUMMARY

In 1944 and 1945, sugar beets grown in the Imperial Valley were lifted, topped, and exposed to conditions of high temperatures and rapid drying, such as commonly occur at the time of harvest in this area. Samples were taken at intervals of two days in 1944 and one day in 1945, and analyzed for harmful nitrogen, sucrose, reducing sugars, and raffinose. Samples taken in 1945 were also analyzed for soluble nitrogen. Harmful nitrogen increased significantly during the first two days of drying. Soluble nitrogen also increased during the first two days of drying, but after this the value fluctuated until the end of the experiment. Sucrose and raffinose decreased at a constant rate from the end of the first two-day period of drying to the end of the test. This loss was the result of inversion as shown

by the increase in the reducing sugars. The reducing sugars increased at a constant rate after the first days of drying until the end of the experiment.

Temperatures in the Imperial Valley of California are much higher during the harvest period than in most of the sugar beet areas in the United States. That is why the changes in the contents of chemical constituents of sugar beets, as noted in this experiment, were more rapid than is the case with beets exposed to less drastic conditions. It is quite evident that unless the beets are gathered promptly after harvest heavy losses occur.

The Effect of Burning and Various Fertilizer Treatments on Seed Production of Red Fescue, *Festuca rubra* L.[1]

H. B. Musser[2]

THE RED fescue species is widely adapted for general turf use throughout the entire northeastern and North central sections of the United States. It is used alone or as an ingredient in good commercial seed mixtures for lawn purposes, particularly on shaded areas. Because of the tough character of the turf and its resistance to wear, it is particularly well adapted to sports use and as air field cover. Seed supplies usually have been limited and prices uniformly higher than those of Kentucky bluegrass.

Experimental trials at the Pennsylvania Experiment Station with individual selections of the grass and commercial plantings of 25 to 100 acres in widely separated sections of the state have demonstrated the possibilities for profitable seed production in Pennsylvania. Among the more important factors affecting seed yields are proper fertilization and control of insect and disease injury.

Observations on seed production in both experimental and commercial plantings have indicated that insect and disease injury may be responsible for serious reductions in seed yield. In preliminary studies initiated by Dr. C. C. Wernham, Department of Botany, School of Agriculture, The Pennsylvania State College, in 1941, burning of the dry vegetation in early spring gave some measure of disease control. Results, while too limited to justify conslusions, warranted further investigation of the method. This work was continued by Keil (7)[3] who studied incidence and control methods for the "white head" disease, *Fusarium poae*, on plantings of red fescue at the Pennsylvania Experiment Station. He concluded that the fungus is the causal agent, and that one of the grass mites, *Pedeculopsis graminum*, is closely associated with the spread of the disease. He reports highly significant reductions in number of diseased heads by spring burning. The burning treatment did not show a significant increase in seed yields under the conditions of his experiments.

Several workers have studied the effects of fertilizer treatments upon seed yields of grasses. North and Odland (8) and DeFrance and Odland (3) have reported on the influence of fertilizer mixtures on seed yields of species of bent grasses. Evans (5) and Evans and Calder (6) have studied the effects of fertilizing grasses for seed porduction at the Welch Plant Breeding Station. Burton (2) has reported on fertilizer trials with 10 southern grasses. These workers are in

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[2]Professor of Agronomy.

[3]Figures in parenthesis refer to "Literature Cited", p. 340.

general agreement that applications of nitrogen materially increased seed yields, but that phosphorus and potash, either alone or in combination with nitrogen, had little effect. Burton (1) has reported that burning sods of Bahia and Bermuda grass has resulted in increased seed yield.

MATERIALS AND METHODS

Three series of experiments have been established to study the effect of various burning and fertilizer treatments upon seed yields of red fescue as follows: Series I, spring burning and fertilization under conditions of low soil fertility and limited disease infection; series II, spring burning and fertilization under conditions of good soil fertility and heavy disease infection; and series III, summer burning after seed harvest, followed by fall and spring fertilization under conditions of good soil fertility and heavy disease infection.

SERIES I

This experiment was laid out in the spring of 1945 on a 6-year-old row planting of red fescue. The soil is a sandy loam derived from cherty dolomites which classifies in the Morrison series and has a very low fertility level. The planting received a uniform row application of 250 pounds per acre of a 4–8–4 fertilizer at the time of seeding, and again in the spring of the second seed year. No additional fertilizer was applied in succeeding years.

The experiment consisted of nine treatments as listed in Table 1, randomized on 12-foot burned and unburned strips across the rows in four replications. Individual fertilizer plots included three 12-foot rows, with 3 feet between rows. The following quantities of nitrogen, phosphoric acid, and potassium oxide were applied to individual plots as indicated in Table 1: Nitrogen, 32.5 pounds per acre; P_2O_5, 80.0 pounds per acre; and K_2O, 50.0 pounds per acre.

The inorganic nitrogen source was ammonium nitrate, and the organic source activated sewerage sludge. Superphosphate and muriate of potash, respectively, were used as the sources of phosphorus and potash. Where organic nitrogen was used, the quantities of superphosphate and muriate of potash were adjusted to compensate for amounts of these materials supplied by the carrier.

In 1945 the burning treatments were made on March 30, and fertilizer treatments were applied on April 13. In 1946 the same fertilizer treatments were applied on May 2, but burning was not repeated.

Seed yields were determined by hand harvesting the center rows of each plot in 1945. In 1946, yields were determined from duplicate 3-foot sections of each center row. Observational notes were made following panicle emergence on disease incidence on all plots in both years.

SERIES II

In the spring of 1946 an experiment was set up to determine the effects of burning and fertilization on a 3-year-old row planting of red fescue under conditions of good soil fertility and high disease incidence. The soil is a silt loam of the Hagerstown series in a good state of fertility. The planting had received a uniform row application of 250 pounds of 4–12–4 fertilizer at the time of seeding. No additional fertilizers had been applied prior to the beginning of the tests.

The experiment consisted of application of the nine fertilizer treatments listed in Table 2 on three row plots, each 20-feet long, randomized across triplicate burned areas. Row spacing was 3½ feet. Nitrogen, phosphoric acid, and potassium oxide were applied to individual plots, as outlined in Table 2, in a 1–1–1 ratio at a rate of approximately 40 pounds of each per acre. The source of inorganic nitrogen was sulfate of ammonia and the organic nitrogen source activated sewerage sludge. Superphosphate and muriate of potash, respectively, were used as sources of phosphoric acid and potassium oxide. Where organic nitrogen was used, the quantities of superphosphate and muriate of potash were adjusted to compensate for the amounts of each supplied by the organic carrier. All burnings were made on March 13, 1946, and fertilizers were applied on April 4, 1946.

Seed yields were determined by hand harvesting duplicate 3-foot sections of

the center row of each plot. Observational records were taken following panicle emergence on disease incidence on all plots.

SERIES III

This experiment was laid out in the summer of 1945 to determine the effects on seed yield of summer burning after seed harvest, followed by fall and spring fertilizer applications. The test areas were established on the west side of the same field used for experiments outlined above under series II. Age of the fescue planting, width of row, and disease incidence were as outlined for the series II tests. The general fertility level was somewhat lower on this section of the field, due to previous treatment.

The experiment included 32 rows, each 200 feet long. The entire block was clipped following seed harvest in 1945, and the dried clippings were burned on a solid block of 24 rows in mid-August. A block of eight rows were left unburned. The various fertilizer treatments listed in Table 3 were applied across all burned and unburned rows in four randomized replications.

Nitrogen, phosphoric acid, and potassium oxide were applied in early September on individual plots, as indicated in Table 3, in a 1-1-1 ratio at a rate of 50 pounds of each per acre. Sources of fertilizer materials were the same as outlined for the treatments applied in series II. Fertilizer treatments were repeated in the spring of 1946 (May 1) at one-half the rate of the late summer applications.

Seed yields were measured by hand harvesting duplicate 3-foot sections of every fifth row in the burned section and every second row in the unburned area.

RESULTS

The effects of burning in the three series of experiments are shown in Tables 1, 2, and 3. Spring burning under the conditions of these experiments did not produce significant increases in seed yields (Tables 1 and 2). On the other hand, the differences resulting from summer burning are highly significant (Table 3). It is believed that the very wide differences in favor of the burned over unburned treatments in series III (Table 3) in contrast with a lack of significant differences in series II (Table 2) are due primarily to the more effective disease control resulting from summer burning. Failure of the

TABLE 1.—*Effect of fertilization on seed yields of spring-burned and unburned 6-year-old red fescue planting with less than 10% disease incidence.**

Fertilizer treatment	Pounds of seed per acre			
	Burned		Unburned	
	1945	1946†	1945	1946†
Inorganic N plus P plus K	1.9	156.7	4.5	192.9
Inorganic N plus P	2.5	167.1	16.1	161.0
Inorganic N	0.4	153.0	4.4	152.4
Organic N plus P plus K	2.8	219.1	9.8	207.9
Organic N plus P	5.6	169.0	4.7	186.2
Organic N	2.1	163.5	3.6	177.3
P plus K	0.8	168.4	2.9	143.1
P	2.0	137.0	4.6	137.0
None	2.3	99.3	5.3	91.4

*Burned March 3, 1945. Fertilizers applied April 4, 1945 and May 2, 1946. Disease incidence based on estimates on untreated plots in 1945 and 1946.

†L.S.D. = 29.9 pounds.

spring burning treatments to produce significant results may be due to a combination of variables, most of which are not easily controllable. Among these may be listed (a) failure to secure adequate burn because of a damp and matted condition of the vegetation, (b) possible injury to seed head primordia before conditions for burning became favorable, and (c) injury to crowns and new growth that is not repaired within the more limited time between burning and seed development. Further studies of these problems are under way at the Pennsylvania Experiment Station.

TABLE 2.—*Effect of fertilizer treatments on seed yields in the current harvest year of spring-burned and unburned 3-year-old red fescue planting with more than 50% disease incidence.**

Fertilizer treatment	Pounds of seed per acre	
	Burned†	Unburned†
Inorganic N plus P plus K	52.4	81.0
Inorganic N plus P	91.1	82.5
Inorganic N	65.8	91.1
Organic N plus P plus K	42.7	69.1
Organic N plus P	74.0	80.7
Organic N	53.3	51.5
P plus K	44.2	73.4
P	66.7	44.8
None	46.5	69.8

*Burned March 13, 1946. Fertilizers applied April 12, 1946. Disease incidence based on estimates on untreated plots in 1946.
†Differences less than P .05.

TABLE 3.—*Effect of fertilizer treatment on seed yields in the next harvest year of summer-burned and unburned 3-year-old red fescue planting with more than 50% disease incidence.**

Fertilizer treatment	Pounds of seed per acre	
	Burned†	Unburned‡
Inorganic N plus P plus K	343.3	45.1
Organic N plus P plus K	341.5	27.1
Inorganic N	302.0	44.8
Organic N	278.5	35.3
P plus K	260.9	32.2
Nothing	204.3	31.6

*Burned August 21, 1945. Fertilizers applied September 9, 1945, and May 1, 1946. Disease incidence based on estimates on untreated plots in 1946.
†L.S.D. = 43.0 pounds.
‡Exceeds P. 01.

The results of comparisons of the various fertilizer treatments in series I and III show a significant increase in seed yields for applications of nitrogen alone and the mineral elements P and K over no treatment (Tables I and 3). There is a further significant increase where treatments include all three elements. One exception to this is the failure to secure significant differences between applications of

inorganic nitrogen alone and inorganic nitrogen plus P and K in the 1946 results of series I (2nd column, Table 1). Present information is not sufficient to permit an explanation of this apparent inconsistency.

It is suggested that the failure to secure significant differences from the various fertilizer treatments in series II is due to the obscuring effects of disease which had not been controlled in time to influence the current season seed crop. It will be necessary to follow this experiment through the second season to determine the validity of this explanation. The results, however, are of interest and value as evidence that the time of burning has a direct relationship to its effectiveness. Unfortunately, the results of the tests in 1945 of the series I experiment (Table 1) do not contribute any information on this problem. Since disease was not an important factor, it might be expected that effects of fertilizer treatments would be in the same order as for 1946. The almost complete failure of the seed crop in the 1945 season eliminate the results from consideration in this connection. Seriously reduced seed setting was quite common on many of the earlier maturing grasses in this year. Unseasonable warm weather in late February and early March, followed by heavy freezes, apparently caused serious injury to primordia, particularly on soil where the natural fertility level was low.

DISCUSSION

The results of the present experiments suggest strongly that the increase in seed yields due to burning are directly related to a reduction in disease or insect injury, or both. Additional research is under way to make time of burning comparisons and to secure added information on correlation of seed yields with disease incidence and insect populations. These experiments include periodic tests of control sprays in addition to burning treatments. Further work, also, is necessary to determine the optimum rates of fertilization for maximum seed production at different soil fertility levels.

A comparison of the seed yields for the organic and inorganic nitrogen treatments do not show significant differences for these two classes of fertilizers. There was, however, a very appreciable difference observed in the quality of straw produced by the two treatments. Rows receiving the organic nitrogen produced stiff straw that held the panicles in an upright position. In contrast, the seed stalks on the inorganic nitrogen treatments showed a decided tendency to bend over so that the seed heads, particularly those on the outer edges of the row, frequently rested on the ground surface between the rows. While this condition obviously would not be reflected in seed yields obtained by hand harvesting, it is believed that it would result in material yield reductions where machine harvesting was employed.

SUMMARY AND CONCLUSIONS

Summer burning following seed harvest materially increased seed yields of red fescue the following year on plantings where disease infection was severe.

Spring burning did not increase seed yield on the current season crop under conditions of severe disease infection.

Where disease infection was slight, spring burning did not increase seed yields in the second season following the burning treatment.

First year results of the experiments showed that phosphorus and potash applied at rates of 40 to 80 pounds of P_2O_5 and K_2O per acre significantly inceased seed yields over no treatment. Inorganic and organic nitrogen alone, applied at rates of 40 to 60 pounds per acre, produced similar increases in seed yield.

Where P and K were added to the nitrogen applications, seed yields were significantly higher than for nitrogen alone.

No significant differences in seed yield were obtained between treatments with organic and inorganic nitrogen carriers, but the observed quality of the straw was more desirable with the organic nitrogen fertilizer.

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Notes

PRE-EMERGENCE CONTROL OF WEEDS IN CORN WITH 2, 4-D

PRE-EMERGENCE control of weeds has been investigated by Templeman in England.[1] He found that 2–methyl–4–chloro-phenoxy-acetic acid applied at the rate of 2 pounds per acre on fields seeded to spring oats and barley resulted in no injury to those crops and gave a high degree of weed control. The barley varieties varied somewhat in susceptibility to injury by this herbicide.

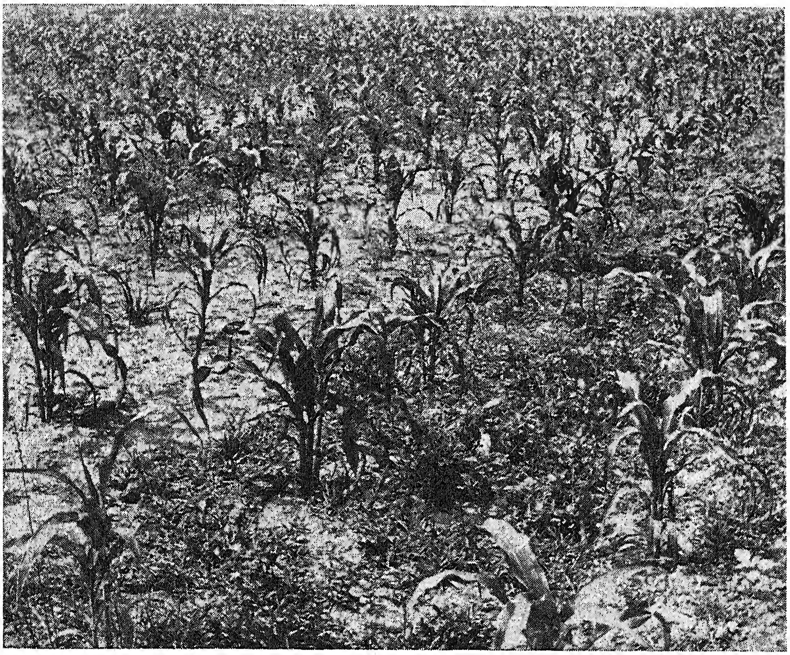

FIG. 1.—Showing the weeds in the checks (right) as against the bareness of the adjacent plot where 2.7 pounds of 2,4-D were applied per acre. Note that the corn was doing equally well on both strips. Photo taken 5 weeks after treatment.

A preliminary experiment was set up in the summer of 1946 at New Brunswick to investigate the possibility of using 2, 4–D for pre-emergence weed control in corn production. Five corn inbreds—J47, Hy, 38–11, Wf9, L317—and seven corn hybrids—N. J. 2, N. J. 4, Ohio C 88, U. S. 13, Pioneer 332, Ohio K 24, and Funk G 94—were planted in two-row strips crossed by three rates of 2, 4-D application. Separating the rates of application were two-row untreated strips. The three rates used were 2.7, 5.5, and 9.1 pounds of 2,4-D free acid per acre. The lowest rate was applied as dust and the other two in solution.

[1]TEMPLEMAN, W. G. Selective weed control by plant growth promoting substances. Jour. Min. Agr., 53:105–108. 1946.

The corn was planted May 31 and 2, 4-D applied to the soil surface June 7, two days before seedlings were up. Observations and notes made on June 20 (Table 1) recorded the effect of the treatments on the corn and weeds (Fig. 1). A corn plant was judged affected when the sheath of the first true leaf was abnormally tight, elongated, and chlorotic, and the seedling curved unnaturally to one side.

TABLE 1.—*Effect of various rates of 2,4-D on five inbred and seven hybrid corns.*

Test plant	Percentage of plants unaffected		
	2.7 pounds as dust	5.5 pounds in solution	9.1 pounds in solution
Inbreds			
J47	50	58	0
Wf9	92	67	25
38-11	56	0	0
Hy	0	67	0
L317	80	67	33
Inbred av	56	52	12
Hybrids			
N. J. 2	100	60	30
N. J. 4	100	55	25
Ohio C 88	100	75	50
U. S. 13	100	50	35
Pioneer 332	100	60	20
Funk G 94	100	80	30
Ohio K 24	85	60	60
Hybrid av	98	63	36
Affected plants which survived, %	100	25	50

The discrepancy in the response of the Hy inbred could possibly have been due to faulty distribution of the applied material.

Annual grasses as well as broad-leafed weeds were effectively controlled for about 6 weeks. At such time the corn was past being given much competition by the new weeds.

The weather records showed that it rained on three different days the first week after the 2, 4-D was applied. The total rainfall was 1 inch.

The total yields from each treated strip indicate that 2.7 pounds of 2, 4-D effectively controls weeds and does not have any detrimental effect on corn production.—J. C. ANDERSON and D. E. WOLF, *New Jersey Agricultural Experiment Station, New Brunswick, N. J.*

THE SCARIFICATION OF VARIOUS LEGUME SEEDS WITH A DISC SCARIFIER

OBSERVATIONS are noted in connection with numerous pilot tests to improve the germination of various legume seeds at the Soil Conservation Service Nursery at Chapel Hill, N. C. Many of the legumes bear a high percentage of hard seeds, of course, which require special treatment for good germination.

Among the means used to increase germination, mechanical scarification was the most practical. However, with most commercial scarifiers, it is often impossible to scarify without either overdoing and seriously damaging the seeds or underdoing the job. The best mechanical scarifier tested was a modification of the Denbigh disc scarifier[1] developed by Tabor[2] especially for the scarification of kudzu, *Pueraria thunbergiana* Benth., seed. This was more effective than five different makes of commercial scarifiers tested, or sulfuric acid.

This machine consists essentially of a series of 18 ¼-inch plywood discs covered with emery paper, mounted about 1 inch apart on a shaft inclosed in a metal cylindrical seed chamber. It has worked well on several species of hard-seeded legumes. It scarifies by gently grinding the relatively thick, brittle seedcoats without cracking the most fragile ones. For best results the seeds should be dehulled and cleaned. One man can scarify about 60 pounds of seed per hour. The seed chamber should be filled about one-third full of seed, i. e., about 15 to 20 pounds, and the shaft driven at approximately 600 r.p.m. for 3 to about 20 minutes, depending on the nature of the seed and its seedcoat.

The degree of scarification of individual seeds is strikingly uniform except for a few in the bottom of the chamber which might not be picked up by the rapidly turning discs. This is remedied by rotating the seed chamber all the way over and back about three times during the processing of each batch. Disadvantages of this machine are (a) poor dehulling of seeds and (b) a slow rate of scarification.

Tabor[3] also developed a small single-disc machine of approximately a half-pound capacity which worked well on small seed lots. This machine was also useful in determining the proper time interval and r.p.m. for scarifying in the larger machine described above.

In connection with these scarification tests it was found that a low-power microscope or lens, preferably a binocular dissecting microscope, can be very useful in determining the proper degree of scarification. Thus, by examining samples at frequent intervals when starting on a new seed lot it is possible to prevent considerable wastage due to over-scarification or too little scarification. Seeds are rubbed between the hand to remove any dust and are then examined under the microscope. Properly scarified seeds show a markedly grated effect on their surfaces, especially at the tips of bulges or other points which extend outward from the main body of the seed.

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[1]Jour. For., 33:66–74, 1936; 35:396–398, 1937.
[2]Jour. Amer. Soc. Agron., 34:860–861, 1942.
[3]Jour. Amer. Soc. Agron., 35:256-257. 1943.

Elongated seeds, especially those with tapered ends, are more easily over-scarified than others, since excess scratching may occur at the ends and may even result in a part of the seedcoat being sloughed off.

During the winters of 1942, 1943, and 1944 tests were made to determine the effect of disc scarification on the swelling and germination of several of the legumes. The results are shown in Table 1. All lots of seed had been recently harvested and the tests were performed immediatey following scarification. The seeds were sown in

TABLE 1.—*Effect of disc scarification upon the swelling and germination of several different legume seeds, winter months, 1942, 1943, and 1944.*

Species	Condition of seed	Treatment	Percentage of seed swelled in water after 5 days	Percentage of seed germinated in sand flats in the greenhouse after	
				7 days	14 days
Aeschynomene americana L. (sensitive joint vetch)	Unhulled	Unscarified	—*	0.0	0.0
	Hulled	Unscarified	—	0.0	2.0
	Hulled	Disc scarified 3 minutes at 560 r.p.m.	—	26.0	56.0
Alysicarpus vaginalis (L) DC. (Alyce clover)	Hulled	Unscarified	—	0.0	0.5
	Hulled	Disc scarified 3 minutes at 560 r.p.m.	—	—	22.0
Crotalaria incana L.	Hulled	Unscarified	6	1.0	—
	Hulled	Disc scarified 15 minutes at 650 r.p.m.	97	96.0	—
Crotalaria spectabilis Roth. (showy crotalaria)	Hulled	Unscarified	66	31.0	42.0
	Hulled	Disc scarified 16 minutes at 575 r.p.m.	88	40.0	61.0
	Hulled	Disc scarified 20 minutes at 575 r.p.m.	97	—	—
Lespedeza cuneata (Dum. deCours) (sericea lespedeza) G. Don.	Unhulled	Unscarified	11	—	10.6
	Hulled	Scarified in commercial scarifier "D"	46	23.3	54.0
	Hulled	Scarifier "D" processed, subsequently disc scarified 10 minutes at 575 r.p.m.	80	67.3	80.0
Pueraria thunbergiana (S. & Z.) Benth. (kudzu)	Hulled	Unscarified	—	2.6	31.3
	Hulled	Disc scarified 10 minutes at 575 r.p.m.	—	36.6	52.6

*No count made.

flats of fine, unsterilized sand in the greenhouse and kept moist throughout the tests. Samples of 50 seeds each were randomized and planted in triplicate in the case of crotalarias, sericea lespedeza, and kudzu, and in duplicate in the other tests. A small amount of damping-off occurred. The low germination of kudzu was due primarily to the relatively high content of immature and faulty seeds. The percentage of immature seeds was not determined for the seed lot tested, but an analysis of 70 pounds of kudzu harvested in widely separated locations in North Carolina in 1943 was apparently similar and its analysis was as follows: (a) Plump-speckled (mature) seed, 40%; (b) mature-sized but unspeckled seed, 25%; and (c) "flat" seed of questionable capacity to produce seedlings, 35%.

Other results not shown in Table 1 were as follows: Disc scarification of *Lathyrus sphaericus* (a winter pea) seed for 10 minutes at 800 r.p.m. increased the swelling in water from 14% to 96% after 5 days and of *Lupinus cumicola* Small (sky-blue lupine) from 8% to 100% after 3 days. The effect of 5 minutes of disc scarification at 600 r.p.m. on unhulled Korean lespedeza seed was to increase its swelling in water from 31% to 73% after 1 day and from 73% to 95% after 5 days; on hulled *Trifolium hirtum* (rose clover), 5 minutes at 600 r.p.m. increased the swelling from 61% to 99% after 5 days in water.

Field plantings of seed lots varying from a few ounces to several hundred pounds treated in the disc scarifiers have borne out the efficacy of the machines and the methods used. For example, in 1945, 190 pounds of kudzu seed were disc scarified as shown for kudzu in Table 1 and drilled in 3-foot rows on approximately 25 acres for seedling production. The uniformity of emergence and development of the seedlings and the overall stand were much superior to the results of former seasons when kudzu seed was scarified in commercial machines. Similarly, in 1944, 150 pounds of *Crotalaria spectabilis* seed were disc scarified for 20 minutes at 575 r.p.m. and drilled in 3-foot rows on 17 acres for seed production. The plantings were made from early May to early July. In all fields the emergence and development of the plants were strikingly uniform, so that the seeds ripened evenly and the problem of machine harvesting was reduced to the minimum that could be expected.—ANDREW C. MATHEWS, *Forest Service, U. S. Dept. of Agriculture, Tifton, Ga.*

GRASSHOPPER CONTROL WITH DUSTS AND SPRAYS FOR PROTECTION OF EXPERIMENTAL PLOTS[1]

IN conducting experiments with forage crops on small plots, considerable grasshopper damage to stands has occurred on the Agronomy Farm near Fort Collins, Colorado. This damage probably occurs at other experiment stations. The use of poison bait for the control of grasshoppers on experimental plots at Fort Collins has never been satisfactory. Occasionally good kills have been obtained, but generally it has been ineffective. During the summer of 1946 various dusts and sprays were applied to ascertain their value in protecting forage plots from severe damage by the heavy infestation of grasshoppers feeding on them. Certain of the compounds applied were very effective in the killing of adult grasshoppers in 1946, and reduced populations to such low numbers that damage was negligible. Since these trials were so encouraging, the results are reported here.

EXPERIMENTAL METHODS

Various kinds of dusts and sprays were applied to alfalfa and other forage plots during August and September of 1946. The grasshoppers were adults, mostly two striped, differential, and red-legged species. The dusts were applied with hand rotary dusters while the sprays were applied with a power sprayer. The concentration of grasshoppers on the areas was approximately six per square yard. Control is expressed in percentage killed within certain periods of time. The percentage mixtures of insecticides and carriers are reported in Table 1 as well as the rate per acre of mixtures used. The hexachlorocyclohexane contained 10% of the gamma isomer. The velsicol 1068 and Colorado 9 were dissolved 1 pound in 1 quart of xylene with 50 cc of triton 100 emulsifier added. This was then diluted with 50 gallons of water.

RESULTS

The results are reported in Table 1 for dusts containing DDT, Sabadilla, Velsicol 1068, hexachlorocyclohexane, 3956 (Hercules Powder Company), Trichlorethane, and Colorado 9.

Hexachlorocyclohexane.—The results show that control of adult grasshoppers in 1946 was excellent with the dust of hexachlorocyclohexane, and that nearly 100% control was obtained within 1 to 7 days when 10% dust was applied at the rate of 20 pounds of this mixture an acre. When the 5% mixture was applied at 20 pounds no control resulted, but an application of 50 pounds of 5% mixture was more effective than 20 pounds an acre of the 10% dust. Ten per cent hexachlorocyclohexane at 20 pounds an acre and 5% hexachlorocyclohexane at 50 pounds an acre were very effective. The hexachlorocyclohexane used in the 5% mixture at 20 pounds an acre had been stored 1 year at room temperature.

Velsicol 1068.—This material gave nearly 100% control in 8 days or less when applied as a 5% dust at 20 pounds an acre, or as a spray (1 pound in 50 gallons) at 50 gallons an acre.

3956 (Hercules Powder Company).—This material as a 20% dust at

[1]Contribution from the Agronomy and Entomology Sections, Colorado Experiment Station. Published with the approval of the Director of the Colorado Experiment Station, Fort Collins, Colorado, as Scientific Series Paper No. 239.

TABLE I.—*Results of grasshopper control with various dusts and sprays on the Agronomy Farm Near Fort Collins, Colorado, in 1946.*

Insecticides	Application in lbs. per acre	Date applied	Crop applied to	Degree of control
		Applied With Hand Duster		
DDT (25% in pyprophyllite)	25	Sept. 11	Alfalfa	25% in 48 hours; 50% in 8 days
Sabadilla (20% in pyrophyllite)	20	Aug. 19	Alfalfa	None
Velsicol 1068 (5% in pyrophyllite)	20	Sept. 11	Alfalfa	50% in 48 hours; nearly 100% in 5 days
Hexachlorocyclohexane (5% in pyrophyllite)	20	Aug. 20	Alfalfa	None
Hexachlorocyclohexane (5% in pyrophyllite)	50	Sept. 25	Alfalfa	Dying 3 hours later; nearly 100% in 24 hours
Hexachlorocyclohexane (10% in pyrophyllite)	20	Sept. 11	Alfalfa	75% in 24 hours; nearly 100% in 1 week
Hexachlorocyclohexane (10% in pyrophyllite)	20	Sept. 11	Alfalfa	75% in 24 hours; 90% in 48 hours; nearly 100% in 1 week
Hexachlorocyclohexane (10% in pyrophyllite)	20	Sept. 25	Alfalfa in 3-foot rows	Dying 1 hour later; nearly 100% in 24 hours later
Hexachlorocyclohexane (10% in pyrophyllite)	20	Sept. 25	Alfalfa in 3-foot rows	Dying 1 hour later; nearly 100% in 24 hours later
Hexachlorocyclohexane (10% in pyrophyllite)	20	Sept. 25	Alfalfa in 3-foot rows	Dying 1 hour later; nearly 100% in 24 hours later
Hexachlorocyclohexane (10% in pyrophyllite)	20	Sept. 23	Alfalfa	50% kill in 48 hours; redusted Sept. 25 at same rate causing 95% kill on Sept. 26
3956 (Hercules Powder Co.) (20% in pyrophyllite)	20	Sept. 25	Ladino Clover	75% in 24 hours; 95% in 8 days
Trichlorethane (10% in Franite Clay)	20	Sept. 25	Stubble	75% in 24 hours; 95% in 8 days
		Sprays		
Colorado 9 (1 lb. in 50 gal.)	50 gal.	Sept. 14	Stubble	40% in 8 days
Velsicol 1068 (1 lb. in 50 gal.)	50 gal.	Sept. 14	Stubble	98% in 8 days

20 pounds an acre gave 75% control in 24 hours and 95% control in 8 days.

Trichlorethane.—This material as a 10% dust at 20 pounds an acre gave 75% control in 24 hours and 95% control in 8 days.

Colorado 9.—This material as a spray (1 pound in 50 gallons) at 50 gallons an acre gave 40% control in 8 days.

DDT.—This material as a 25% dust at 25 pounds an acre gave 25% control in 48 hours and 50% control in 8 days.

Sabadilla.—As a 20% dust at 20 pounds an acre Sabadilla was ineffective. The Sabadilla used in this test had been stored 1 year at room temperature.

DISCUSSION

It was observed that alfalfa plants spaced 3 feet by 3 feet or alfalfa rows spaced 3 feet apart were effectively protected with 10% hexachlorocyclohexane at 20 pounds an acre. The dust was applied so that much of it lay on the surface of the leaves. As the grasshoppers moved about alighting on leaves covered with dust, they received an additional dusting and were killed quicker than where less dust covered the leaves of the vegetation.

Since it is not known whether any of these materials might poison livestock, they are not recommended for general farm use. However, those effective for grasshopper control might be used on experimental farms to protect valuable materials from grasshopper damage. —Ralph M. Weihing and J. L. Hoerner, *Colorado A. & M. College, Fort Collins, Colorado.*

Book Reviews

CONCISE CHEMICAL AND TECHNICAL DICTIONARY

Edited by H. Bennett. Brooklyn: Chemical Pub. Co., Inc. XXXIX+ 1055 pages. 1947. $10.

TECHNICAL terms used even in any single branch of science are multiplying at such a rate that it is by now difficult for anyone to follow the literature of recent developments without some aid. A further confusing factor is the ever-increasing use of trade names and those of proprietary products, especially in the biochemical and pharmaceutical fields. For these reasons the use of chemical dictionaries is becoming more and more necessary. Bennett's concise dictionary contains some 50,000 definitions. The nomenclature of organic compounds is a most welcome part of any volume of this sort and the glossary of radicals and illustrations of organic ring systems are logical complements of this discussion.

The scope of terms included seems to be sufficient for everyday work, although there is no limit to which such a dictionary could be expanded. The printing is exceptionally clear and readable, a gratifying change from the eye-breaking variety of fine print used in many dictionaries. The binding of the volume is sturdy. The volume will provide much help to those in contact with chemical terms, but especially to those who work in related fields. The editor should be congratulated on this latest effort of his to create order in the hydra-headed science of chemistry.—Z. I. KERTESZ.

LANGE'S HANDBOOK OF CHEMISTRY

Sandusky, Ohio: Handbook Publishers, Inc. Ed. 6, 2,082 pages. Fabricoid. 1947. $7.

THERE are several changes in this new edition of Lange's Handbook. The important table of Physical Constants of Inorganic Compounds has been completely revised and there are 14 new chapters, mostly dealing with physical constants. Two tables giving data on pipes have been dropped. A most welcome trend in the Handbook is the increasing attention given to nomenclature, synonyms, and definitions of terms which make it a far cry from the handbooks of olden days containing only tabulated material. The reviewer is still impressed by both the size and organization of the index. It is difficult to see how anybody touching in any manner in the fields of chemistry and physics can afford to be without the aid of this splendid handbook.—Z. I. KERTESZ.

Agronomic Affairs

STUDENT SECTION ESSAY CONTEST FOR 1947

IN accordance with the announcement made in the last report of the Committee on Student Sections, Volume 38, pages 1124 to 1125, this JOURNAL, a student essay contest is being sponsored by the American Society of Agronomy in 1947. Doctor M. A. McCall has donated $100 for use as cash prizes for the best papers.

Students presenting top-ranking essays will receive awards as follows: First place $30, second $20, third $15, fourth $10, fifth $7, sixth $5, and seventh $3. In addition, the three high men shall receive appropriate medals and a year's subscription to the JOURNAL of the American Society of Agronomy.

Any undergraduate student is eligible to enter this contest. Students graduating before September 1, 1947, must submit their papers prior to graduation. A certificate of undergraduate classification, signed by the proper college authority, must accompany each paper.

Papers should be typed, double spaced, and not less than 3,000 nor more than 3,500 words in length. An abstract of not more than 500 words must accompany each paper. Abstracts should be prepared carefully as it is planned to publish the best. Failure to submit an abstract will disqualify an essay.

The title of the essay shall be: "Effect of Soil Fertility on the Quality of the Wheat Crop".

The Committee suggest that where several papers are entered from a given institution, the local representatives of the Society review the essays and submit only the best articles. This will save work for the committee and reduce mailing expense.

Rating of essays is to be done by two or more members of the Society at each of three different schools. The winners of the contest will be announced at the meeting of the American Society of Agronomy in the fall of 1947.

Essays must be in the hands of the Chairman of the Committee, G. H. Dungan, 210 Davenport Hall, Urbana, Ill., not later than August 1, 1947. Agronomists are urged to encourage student participation in this contest.

SUMMER MEETING OF CORN BELT SECTION

THE summer meeting of the Corn Belt Section of the American Society of Agronomy will be held in Kansas June 9, 10, and 11, 1947. The group will assemble at Manhattan, Kansas, Monday morning, June 9, at 9:00 a.m., and leave for the Fort Hays Branch Experiment Station, Hays, Kansas, about noon June 10. The meeting will continue until about mid-afternoon of June 11.

The Spencer Chemical Company has invited the group to visit their nitrogen plant near Pittsburg, Kansas. Arrangements have been made for a trip through the plant on June 12. Those interested in pasture improvement are planning for a special meeting after the conclusion of the Hays trip.

The Central Alfalfa Improvement Conference will meet on June 10.

THE WESTERN SOCIETY OF SOIL SCIENCE

THE Western Society of Soil Science will hold a summer meeting in San Diego, California, on June 16 to 18, 1947, in conjunction with the Pacific Division of the American Association for the Advancement of Science. Doctor O. J. Kelley, Bureau of Plant Industry, is President of the Society; Dr. G. O. Baker of the University of Idaho, Vice President; and Dr. H. B. Peterson, Utah State Agricultural College, Secretary and Treasurer.

SUMMER MEETING OF NORTHEASTERN BRANCH OF THE SOCIETY

THE Northeastern Branch of the American Society of Agronomy will hold its 1947 summer meeting at the University of Vermont and at Macdonald College, Quebec, on June 23, 24, and 25, according to Paul R. Miller, University of Vermont, Secretary-Treasurer of the Branch.

Approximately 125 agronomists, and others interested in agronomy, make up the Northeastern Branch which includes all of New England and the states of Virginia, Delaware, Maryland, West Virginia, New Jersey, Pennsylvania, and New York. The summer meetings are rotated among the states, giving the agronomists an opportunity to observe field experiments as well as the types of crops, soil, and climate in each of the states in the region.

The first day of the 1947 meeting will be devoted to a tour of soil and crop experiments in the lower Champlain Valley and on the University of Vermont farm. The second day will be spent enroute to Macdonald College, which is a branch of McGill University and is located about 25 miles west of Montreal at Ste. Anne de Bellevue, Quebec. One stop enroute will be made at the Brigham Farm in St. Albans, Vt., on which soil and cropping practices will be observed as well as the Jersey herd which has gained national and international fame for its high production.

The third day will be spent at Macdonald College and vicinities, inspecting fertilizer, forage, grain, and animal nutrition experiments. Arrangements have also been made with the experiment station staffs at Lennoxville, Quebec, and at Ottawa to look over their experimental work on Thursday and Friday for those interested.

Program details and itinerary are being worked out by the agronomy staffs at each of the host institutions and will be announced at a later date.

SUMMER MEETING OF WESTERN BRANCH OF THE SOCIETY

THE summer meetings of the Western Branch of the American Society of Agronomy and of the Alfalfa Improvement Conference, Western Group, will be held at the Colorado A. & M. College, Fort Collins, Colorado, July 9 to 11, inclusive. All interested workers are invited to attend these meetings. Housing, at reasonable rates, will be available on the campus. Send reservations to Ralph M. Weihing, Agronomy Department, Colorado A. & M. College, Fort Collins, Colorado.

NEWS ITEMS

DOCTOR BYRON T. SHAW has been appointed Assistant Administrator of Agricultural Research, U. S. Dept. of Agriculture, to succeed W. V. Lambert who became Administrator last October.

—A—

ACCORDING TO *Science*, the University of Illinois has accepted a grant from the Herman Frasch Foundation for investigating the possibilities of increasing organic matter of soils under practical crop conditions and determining the role of organic matter in the production of exceptionally high yields of corn and other crops. The investigations will be conducted under the direction of R. H. Bray, E. E. DeTurk, and O. H. Sears.

—A—

THE UTAH AGRICULTURAL EXPERIMENT STATION, according to a note in *Science*, has been selected by the U. S. Dept. of Agriculture as a site for a legume seed research station for investigation of problems of production of alfalfa and other forage crop seed. F. E. Todd and G. E. Bohart have been assigned to work on pollinating insects, F. V. Lieberman and S. K. Snow on destructive insects, and J. W. Carlson and M. W. Pedersen on seed production and improvement problems.

—A—

GEORGE L. MCCOLM, formerly located at Emporia, Kansas, has recently been transferred to Window Rock, Arizona, and placed in charge of the soil moisture conservation apparatus on the Navejo Indian Reservation.

—A—

DOCTOR VERNON C. JAMISON has been appointed to the position of Soil Physicist with the U. S. Dept. of Agriculture Division of Soils, Fertilizers, and Irrigation. He will make his headquarters at Auburn, Ala., where he will carry out studies on soil tilth and soil physical properties in cooperation with the Department's Regional Tillage Machinery Laboratory and the Department of Agricultural Engineering of the Alabama Agricultural Experiment Station.

—A—

DOCTOR LOUIE HENRIE SMITH, Chief Emeritus in Charge of Publications of the University of Illinois Soil Survey and Professor Emeritus of Plant Breeding, University of Illinois, died at his home in Urbana, Ill., on January 30th. Doctor Smith was a charter member of the American Society of Agronomy and for many years was active on committees and at the annual meetings of the Society. He retired in 1940.

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DOCTOR M. J. FUNCHESS of the Alabama Agricultural Experiment Station was elected President of the Association of Southern Agricultural Workers at the last meeting of the Association.

—A—

DOCTOR CLARENCE R. DORMAN, since 1938 Director of the Mississippi Agricultural Experiment Station and coordinator of agricultural education for the Mississippi State College, died of a heart attack at his home on February 9th.

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A Simplified Method for Establishing the Three-Point Order of Genes from F_3 Data[1]

Luther Smith[2]

THE method outlined herein for determining the linear order of genes from F_3 data seems to have considerable merit because of time-, labor-, and space-saving features. It is especially useful where the genes are closely linked, because only a few crossovers will establish the order.

For example, let it be assumed that linked factors *a* and *b* for two seedling and factor *c* for a mature-plant character are being tested for their order in the chromosome. If *a* and *b*, e. g., are in coupling, the genotypic constitution of the F_1 would be as follows, depending on the order of the genes:

1	2	3
$a\ b\ C$	$a\ C\ b$	$C\ a\ b$
$A\ B\ c$	$A\ c\ B$	$c\ A\ B$

Only the singly recessive *c c* F_2 plants need be harvested and tested in F_3 for the seedling characters determined by *a* and *b*. If there has been no crossover, the F_2 plants will be *A A B B c c*, but a crossover (ignoring doubles) could occur in either of the intervals between the genes, resulting in plants with the constitutions indicated below.

	1	2	3
Parental (noncrossover) chromosome	$A\ B\ c$	$A\ c\ B$	$c\ A\ B$
Single crossover in the first interval	$a\ B\ c$	$a\ c\ B$	$c\ a\ b$
Parental (noncrossover) chromosome	$A\ B\ c$	$A\ c\ B$	$c\ A\ B$
Single crossover in the second interval	$a\ b\ c$	$A\ c\ b$	$c\ A\ b$

With a little consideration it becomes apparent that by determining the genotypic constitution of the singly recessive plants and assigning them to the proper crossover classes indicated above, the crossovers in the two intervals between the genes will establish positively the order of the genes.

An example will be given to show how the method has been used on diploid wheat. The genes *e-2* for early maturity; *yg*, for yellow-green

[1]Published as Scientific Paper No. 692, College of Agriculture and Agricultural Experiment Stations, Institute of Agricultural Sciences, State College of Washington, Pullman, Wash. Received for publication December 14, 1946.

[2]Collaborator, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture.

seedling; and *yx-2*, for virescent seedling were known to be linked. An F_2 population of the cross *e-2 yg* × *yx-2* was grown in the field and the early plants harvested to test in the greenhouse for the seedling characters. Of 52 early plants, 37 were of the parental constitution e e yg yg Yx Yx; 9 were e e Yg yg Yx yx; and 6 were e e Yg yg Yx Yx. In no plant were yg and yx in coupling.

The results may be summarized as follows:

Genotypic constitution of the F_1 hybrid—

1		2		3
e yg Yx		*e Yx yg*		*Yx e yg*
	or		or	
E Yg yx		*E yx Yg*		*yx E Yg*

Genotypic constitution of crossover types (early plants only)—

	1	2	3
Parental (noncrossover) chromosome	*e yg Yx*	*e Yx yg*	*Yx e yg*
Single crossover in the first interval	*e Yg yx*	*e yx Yg*	*yx e yg*
Number of F_2 individuals observed	9	9	0
Parental (noncrossover) chromosome	*e yg Yx*	*e Yx yg*	*Yx e yg*
Single crossover in the second interval	*e yg yx*	*e Yx Yg*	*Yx e Yg*
Number of F_2 individuals observed	0	6	6

The 9 e e Yg yg Yx yx plants cannot be used to distinguish between orders 1 and 2 (and are listed under both) and the 6 e e Yg yg Yx Yx plants do not distinguish between orders 2 and 3. However, all 15 of the crossover individuals can be accounted for by assuming that single crossovers occurred in order 2. To be able to account for all of them, if either order 1 or 3 is assumed to be the correct one, would require that either 6 or 9 of them be double crossovers. It would be highly improbable that there would be that many double crossovers in comparison with the number of single crossover and the 37 e e yg yg Yx Yx noncrossover plants.

Thus, evidently the order of the genes is *e-2 yx-2 yg*. The order was established with relatively small populations and little work.

There is some advantage in using the method with three seedling or three mature-plant characters, or in the case where two mature-plant and one seedling character are involved. In the latter case, plants with either or both of the mature-plant characters can be harvested and tested for the seedling character. Each kind of singly recessive plant can be tested for the second mature-plant character. If the factors for the mature-plant characters came into the cross in coupling (and were fairly closely linked), the order of the genes can be established with considerable certainty by testing singly and doubly recessive plants for the seedling character only.

In using the method certain improbabilities are taken advantage of. First, it is unlikely that both of the chromosomes concerned will have a crossover. Second, double crossovers between the three genes are unlikely unless the crossover distances are long. If plants do receive both chromosomes with crossovers, or chromosomes with double crossovers, they complicate the data, but can be detected as such by

their rarity in comparison with plants receiving a noncrossover and a single crossover chromosome. They do not invalidate the method.

In describing the method it was assumed that sufficient data were available on the crossover distances, and it was desired only to establish the three-point order. However, information can be obtained from the data on the F_3 progeny tests of singly recessive plants composed of 20 or more individuals for fixing the crossover percentages. Methods and tables for using such data for calculating linkage intensities may be found in papers by Immer[3] and Immer and Henderson.[4]

It is important to note that only a few individuals in a progeny are sufficient to establish the presence of a gene in the F_2 parent, while to have reasonable proof that a gene was not present requires a population of 20. Thus, even if a mutant has low vigor, only a few seeds from a small number of plants may provide satisfactory evidence for establishing the order of three genes.

The method is applicable to classifying plants homozygous for dominant as well as for recessive genotypes. This would be of some importance if homozygous dominant phenotypes were distinguishable from heterozygotes, or if low viability of certain recessive phenotypes made their use impracticable.

Perhaps it should be pointed out that most of the normal F_2 plants are heterozygous for linked factors just as are the F_1 plants. Consequently, it is possible to get material for additional linkage data from the progenies of normal F_2 plants, thus avoiding having to remake the F_1 hybrid.

It might be mentioned, also, that crossovers may be discovered in the F_3 progeny tests of F_2 individuals of normal phenotype that have brought genes into coupling that were in repulsion phase in the F_1. These plants are valuable in establishing crossover values, since these values can be determined accurately with smaller populations from coupling- than from repulsion-phase data, particularly if the linkage is close.

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[3]IMMER, F. R. Calculating linkage intensities from F_3 data. Genetics, 19:119–136. 1934.

[4]IMMER, F. R., and HENDERSON, M. T. Linkage studies in barley. Genetics, 28:419–440. 1943.

The Absorption of Mineral Elements by Forage Plants: I. The Phosphorus, Cobalt, Manganese, and Copper Content of Some Common Grasses[1]

KENNETH C. BEESON, LOUISE GRAY, AND MARY B. ADAMS[2]

IN studies of soil deficiencies related to the occurrence of nutritional troubles in animals, the mineral composition of forages from both good and deficient areas ordinarily serves as an indication of the elements involved. Examination of plant material instead of the soil itself is necessary since there is an almost total lack of data on the relationship between, particularly, the micronutrient element content of the soil and that of the plant. Among the many problems that confront the investigator in this work is the selection of the plant species since it is not always possible to find the same species in two areas. It is well known that species differ in composition. Pierre and Robinson (8),[3] for example, have shown that the phosphorus and calcium concentrations in bluegrass, *Poa pratensis*, and poverty grass, *Danthonia spicata* L. Beauv., were not comparable even when grown on the same soil. Fraps and Fudge (6) reported considerable differences in the phosphorus and calcium concentrations among range pasture grasses. Little is known, however, about the relative mineral concentrations in many other grasses and especially about their micronutrient element contents.

It was the purpose of this investigation to determine the relative quantities of cobalt, manganese, and copper with reference to their phosphorus content in particular, in a number of common grasses grown under uniform conditions.

MATERIALS AND METHODS

Seeds and cuttings were received from the following sources:

Kentucky bluegrass (I), *Poa pratensis* L., strain no. 37-KB114(12). W. M. Myers, U. S. Regional Pasture Research Laboratory.
Kentucky bluegrass (II), strain no. 37-KB120(30). W. M. Myers.
Bahia grass (I), *Paspalum notatum* Flugge, narrow leaf, no. SC20-266. Paul Tabor, Regional Nursery Division, Soil Conservation Service.
Bahia grass (II). Seed produced in South Carolina. E. L. Mayton, No. 24413, Alabama Agricultural Experiment Station.
Natal grass. *Tricholaena rosea* Nees. Florida 1942 seed. Paul Tabor.
Carpet grass, *Axonopus compressus* (Swartz) Beauv. Seed grown in Alabama. Commercial. E. L. Mayton, No. 0-7825.
Dallis grass, *Paspalum dilalatum* Poir. Seed grown in Australia. Commercial. E. L. Mayton, No. 24879.
Johnson grass, *Sorghum halepense* (L.) Pers. Seed grown in Texas. Commercial. E. L. Mayton, No. 24834.
Vasey grass, *Paspalum urvillei* Steudel. Seed grown in Alabama. Pure seed. E. L. Mayton, No. 0-7854.
Tall meadow fescue, *Festuca elatior* L. Seed grown in Oregon. Lot No. 1082, Peter Henderson and Co.

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[1]Contribution from the U. S. Plant, Soil, and Nutrition Laboratory, Agricultural Research Administration, Ithaca, N. Y. Also presented at the annual meeting of the Society at Omaha, Neb., November 20 to 22, 1946. Received for publication December 28, 1946.

[2]Senior Chemist and Agents, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 362.

Bermuda grass, *Cynodon dactylon* (L.) Pers. Seed grown in Arizona. Lot No. 792, Peter Henderson and Co.

Red top, *Agrostis alba* L. Seed grown in Illinois. Lot No. 905, Peter Henderson and Co.

Timothy, *Phleum pratense* L. Seed grown in Iowa. Lot No. 997, Peter Henderson and Co.

Bromegrass, awnless, *Bromus inermis* L. Seed grown in Nebraska. Peter Henderson and Co.

Orchard grass, *Dactylis glomerata* L. Seed grown in Ohio. Lot No. 884, Peter Henderson and Co.

Quack grass, *Agronopyron repens* (L.) Beauv. Albert Dickenson Co.

Para grass, *Panicum barbinode* Trin. Cuttings received from Geo. E. Ritchey, Bureau of Plant Industry, Soils and Agricultural Engineering, Gainesville, Florida.

A Dunkirk fine sandy loam, a soil of moderate fertility occurring in the vicinity of Ithaca, N. Y., was used in the experiment. The soil was sifted through a ¼-inch screen, moistened, and placed in 2-gallon crocks. No fertilizer was applied to the soil. The pots were arranged in the greenhouse in a randomized block design with 17 treatments (species) and 6 replications. Each replication was randomized by the use of Tippett's tables (10).

Seed was planted April 4, 1944, at the rate of 0.1 gram per pot, except as follows: Johnson grass, fescue, Bahia grass, brome grass, and quack grass, 0.3 gram. Vasey grass was planted at the rate of 0.07 gram. Four clones of Para grass were planted in each pot. The grasses were harvested July 11. By the first week in July, Dallis grass, Johnson grass, Vasey grass, fescue, timothy, brome grass, orchard grass, and quack grass had bloomed.

The harvested grasses were dried for 48 hours at 70°C. They were then cut into small pieces with steel shears to avoid any contamination from grinding (7). Analyses for phosphorus were made by the method of Fiske and Subbarow (5), cobalt by the method of Ellis and Thompson (4), copper by the method of Coulson (3) with a preliminary extraction with dithizone, and manganese according to the Official method of the A. O. A. C. (1).

EXPERIMENTAL RESULTS

The data in Table 1 indicate a considerable variation in yield of the grasses. Some of this was due to differences in germination. For example, even though decorticated, the Bahia grasses, Natal grass, Dallis grass, and Johnson grass did not germinate as well as did other grasses such as bluegrass and timothy. The germination of carpet grass was intermediate. For the majority of cases, however, there were actual differences in growth. For example, the Para grass clones produced a very tall and vigorous stand of vegetation in contrast to most of the grasses such as bluegrass and red top.

The analyses of the grasses are presented in Tables 2 to 5 in the descending order of their content of each element. The grasses have also been divided into high, medium, and low groups. The basis for this was in part arbitrary, but essentially two factors were considered, first, the value of the grasses in animal nutrition; and second, groupings that would differ in composition from each other. Clear divisions were not always achieved, but in the case of phosphorus, the low phosphorus group represents those grasses that are borderline in phosphorus content for maintenance of herbivora. On phosphorus-deficient soils these grasses would presumably have too little phosphorus even for maintenance. Somewhat the same situation obtains for the low cobalt group. For manganese and copper, animal requirements are not clearly defined and the groupings are consequently more arbitrary in nature.

TABLE 1.—*Yields of grasses grown on Dunkirk fine sandy loam, first cutting, on moisture-free basis.*

Species	Yield, grams per pot*
Bermuda grass	42.3±2.10
Para grass	40.4±3.19
Natal grass	28.0±1.29
Quack grass	25.7±1.21
Vasey grass	25.3±2.02
Timothy	22.8±1.45
Bahia grass (I)	21.7±1.80
Bahia grass (II)	21.3±1.41
Dallis grass	20.7±1.58
Orchard grass	20.0±0.57
Carpet grass	19.5±0.67
Fescue	18.8±1.27
Kentucky bluegrass (I)	18.0±0.73
Kentucky bluegrass (II)	17.5±0.22
Johnson grass	17.3±1.74
Brome grass	16.8±1.07
Red top	15.3±1.36

*Mean and standard error.

The tables also show which grasses are highly significantly different from each other in composition. Thus, in the third column of each grouping, there is given the name of the grass that differs significantly (at the 1% level) from the grass listed in the first column. Thus, the phosphorus content of Kentucky bluegrass (I) is significantly greater than that of red top. It follows, of course, that Kentucky bluegrass contains significantly more phosphorus than any of the grasses having the same or less phosphorus than red top.

It is clear from the data that there is a considerable range in the composition of species. In the cases of Kentucky bluegrass and Bahia grass there is no indication of a difference due to strain or seed source. This is true of both yields and composition. With the exception of the manganese content, Kentucky bluegrass absorbed the greatest quantities of the elements determined. The manganese content of both red top and orchard grass is significantly higher than that of any other grass. H. A. MacDonald[4] and others (2, 9) have also observed that these grasses normally had a higher manganese content than any other grass studied.

There is no overall correlation of mineral content to yield, although both the Bermuda and Para grasses are low in copper and cobalt and yielded the highest quantity of vegetative matter. In these specific cases, of course, this low content of these elements might be due to a dilution effect. On the contrary, however, Para grass is in the medium phosphorus group and Bermuda is in the medium manganese group.

DISCUSSION

It is evident that a comparative evaluation of soils in relation to troubles in animals cannot be made unless the same or a limited

[4]Private communication.

TABLE 2.—*Phosphorus content of grasses grown on the Dunkirk fine sandy loam, first cutting, moisture-free basis.*

High phosphorus group			Medium phosphorus group			Low phosphorus group		
Species	P, %*	Significantly different from (1% level)	Species	P, %*	Significantly different from (1% level)	Species	P, %*	Significantly different from (1% level)
Ky. bluegrass (I)	0.356±.0080	Red top	Red top	0.269±.0116	Quack grass	Quack grass	0.216±.0043	Vasey grass
Ky. bluegrass (II)	0.349±.0178	Red top	Natal grass	0.264±.0163	Timothy	Bahia grass (I)	0.212±.0082	Vasey grass
Orchard grass	0.306±.0128	Quack grass	Bromegrass	0.256±.0067	Quack grass	Bahia grass (II)	0.208±.0099	
Johnson grass	0.305±.0220	Quack grass	Dallis grass	0.248±.0229	Vasey grass	Bermuda grass	0.208±.0099	
			Para grass	0.242±.0270		Timothy	0.203±.0088	
			Fescue	0.240±.0215	Vasey grass	Carpet grass	0.184±.0064	
						Vasey grass	0.160±.0106	

*Mean and standard error.

TABLE 3.—*Cobalt content of grasses grown on the Dunkirk fine sandy loam, first cutting, moisture-free basis.*

High cobalt group			Medium cobalt group			Low cobalt group		
Species	Co, p.p.m.*	Significantly different from (1% level)	Species	Co, p.p.m.*	Significantly different from (1% level)	Species	Co, p.p.m.*	Significantly different from (1% level)
Ky. bluegrass (II)	0.13±.01	Bromegrass	Bromegrass	0.09±.01	Natal grass	Para grass	0.07±.01	
Ky. bluegrass (I)	0.14±.02	Para grass	Quack grass	0.09±.01	Natal grass	Dallis grass	0.07±.01	
Carpet grass	0.13±.02	Para grass	Bahia grass (I)	0.08±.01		Bermuda grass	0.07±.01	
			Johnson grass	0.08±.01		Natal grass	0.05±.01	
			Bahia grass (II)	0.08±.01				
			Vasey grass	0.08±.01				
			Red top	0.08±.01				
			Timothy	0.08±.01				
			Orchard grass	0.08±.01				

*Mean and standard error.

TABLE 4.—*Manganese content of grasses grown on the Dunkirk fine sandy loam, first cutting, moisture-free basis.*

High manganese group			Medium manganese group			Low manganese group		
Species	Mn, p.p.m.*	Significantly different from (1% level)	Species	Mn, p.p.m.*	Significantly different from (1% level)	Species	Mn, p.p.m.*	Significantly different from (1% level)
Red top	815.5±79.09	Fescue	Carpet grass	194.6±19.95	Quack grass	Quack grass	107.5±5.33	
Orchard grass	564.3±25.24	Fescue	Timothy	192.4±9.63	Johnson grass	Natal grass	105.1±2.88	
Fescue	288.2±14.03	Carpet grass	Vasey grass	188.2±10.55	Johnson grass	Para grass	95.8±5.80	
Bromegrass	260.6±13.76	Timothy	Bermuda grass	176.7±9.07	Ky. bluegrass (I)			
			Bahia grass (II)	174.9±27.48				
			Ky. bluegrass (II)	163.5±9.24	Quack grass			
			Bahia grass (I)	157.5±12.15	Quack grass			
			Dallis grass	156.5±7.40	Quack grass			
			Johnson grass	138.5±8.89	Natal grass			
			Ky. bluegrass (I)	134.7±5.80	Quack grass			

*Mean and standard error.

TABLE 5.—*Copper content of grasses grown on the Dunkirk fine sandy loam, first cutting, moisture-free basis.*

High copper group			Medium copper group			Low copper group		
Species	Cu, p.p.m.*	Significantly different from (1% level)	Species	Cu, p.p.m.*	Significantly different from (1% level)	Species	Cu, p.p.m.*	Significantly different from (1% level)
Ky. bluegrass (I)	21.1±2.33	Johnson grass	Johnson grass	10.5±1.54	Para grass	Quack grass	6.8±0.39	Para grass
Ky. bluegrass (II)	20.4±3.45	Bahia grass (I)	Bahia grass (I)	10.1±1.18	Timothy	Timothy	5.5±0.36	
Carpet grass	15.0±1.83	Bahia grass (II)	Orchard grass	9.9±0.45	Quack grass	Bermuda grass	5.3±0.36	
Bromegrass	12.4±1.48	Quack grass	Bahia grass (II)	8.9±0.24	Quack grass	Para grass	4.5±0.28	
Red top	12.2±2.93		Fescue	8.4±0.97	Para grass			
			Dallis grass	8.0±1.11				
			Natal grass	7.9±0.58	Timothy			
			Vasey grass	7.2±0.93				

*Mean and standard error.

selection of species of grasses are studied. In general, the grasses in any group, high, medium or low, could be used for comparison without regard to species. Thus, the cobalt contents of bromegrass and timothy are comparable, but the cobalt contents of bluegrass and timothy are not. There are notable exceptions, however, to comparing grasses within a group. Thus, the manganese content of red top is significantly greater than that of the fescue. Likewise, the phosphorus content of quack grass is significantly greater than that of Vasey grass although they can most conveniently be grouped together.

A general summary of the grouping of all the species for the mineral elements studied is presented in Table 6. Since phosphorus is the most important element supplied by plants to herbivora, the grasses are listed according to their value in terms of phosphorus supply.

Their ratings under the other elements have been inserted in the appropriate places. Kentucky bluegrass obviously supplies a relatively high quantity of all of the elements studied. The concentration of elements, except that of cobalt, in Dallis grass in this experiment would be adequate for good nutrition. Timothy, the most important forage grass over a large part of the north, is one of the least nutritious so far as mineral content is concerned. Carpet grass, on the other hand, while not one of the best of the southern grasses as a protein and phosphorus supplier, is apparently good with respect to its cobalt, manganese, and copper content.

It is clear that an important contribution to the correction of nutritional deficiencies in animals, particularly those troubles caused by deficiencies of the micronutrient elements, will be an effort to improve the botanical composition of the forage crop. A study of legumes now in progress indicates that both they and the more nutritious

TABLE 6.—*Classification of grasses in relation to the mineral elements they supply.*

Species	Group classification			
	Phosphorus	Cobalt	Manganese	Copper
Ky. bluegrass (I)	High	High	Medium	High
Ky. bluegrass (II)	High	High	Medium	High
Orchard grass	High	Medium	High	Medium
Johnson grass	High	Medium	Medium	Medium
Red top	Medium	Medium	High	High
Bromegrass	Medium	Medium	High	High
Fescue	Medium	Low	High	Medium
Dallis grass	Medium	Low	Medium	Medium
Natal grass	Medium	Low	Low	Medium
Para grass	Medium	Low	Low	Low
Carpet grass	Low	High	Medium	High
Bahia grass (I)	Low	Medium	Medium	Medium
Bahia grass (II)	Low	Medium	Medium	Medium
Timothy	Low	Medium	Medium	Low
Quack grass	Low	Medium	Low	Low
Vasey grass	Low	Medium	Medium	Medium
Bermuda grass	Low	Low	Medium	Low

grasses should be considered in overcoming in part troubles arising from an apparent deficiency of some of the micronutrient elements in soils. One solution of the problem, then, becomes a matter of applying those fertilizer and liming practices with which we already are familiar as a means of growing crops that are naturally higher in nutritive factors.

SUMMARY

The phosphorus, cobalt, manganese, and copper contents of 15 grasses grown under uniform conditions in the greenhouse have been determined. Kentucky bluegrass absorbed the highest quantities of all elements except manganese. Timothy proved to be one of the least nutritious grasses as measured by these constituents. Dallis grass, orchard grass, Johnson grass, and red top are intermediate. There was no overall correlation of composition with yield. Grasses of comparable composition have been grouped for survey purposes.

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Reaction of Varieties and Strains of Winter Wheat to Loose Smut[1]

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LOOSE smut, *Ustilago tritici* (Pers.) Rostr., of wheat causes important economic losses in a number of wheat-growing areas of the United States. In the four leading hard red winter wheat states, Kansas, Oklahoma, Texas, and Nebraska, loose smut caused an average estimated annual loss of 2,577,000 bushels from 1935 to 1939 (4, 5, 13).[3] During the same period, the corresponding average estimated annual loss in the four leading soft winter wheat states, Ohio, Missouri, Indiana, and Illinois, amounted to 1,399,000 bushels. Because of the difficulty of the modified hot water treatment for the control of loose smut, the most practicable method of control is growing resistant varieties. Until very recently, however, there were very few satisfactory resistant varieties available. Pawnee, recently distributed in Kansas, Nebraska, and Oklahoma, is the only hard red winter wheat variety commercially available that is resistant to loose smut. A large proportion of the soft winter wheat varieties grown commercially are very susceptible, although there are a few exceptions. The varieties Kawvale (semihard), Austin, Leap, Currell, Fairfield, Thorne, Trumbull, and Cornell 595 possess various degrees of resistance and have been distributed with such recommendations. A few are highly resistant under all conditions while others are resistant to certain races of loose smut as evidenced by their resistance in some growing areas and their susceptibility in others.

Since 1937, studies to determine varietal reaction to artificial inoculation with loose smut, as the first step in a breeding program to develop resistant varieties, has been under way at Texas Substation No. 6, Denton, Tex. Similar work was undertaken at the Kansas Agricultural Experiment Stations in 1940, and at the Illinois Agricultural Experiment Station in 1942. In order to assemble the results by varieties, the data obtained at the three stations are combined in this paper. A given variety or strain may have been tested at one to three stations from one to seven seasons.

MATERIAL AND METHODS

Three methods of inoculation were used in these tests. The partial vacuum spore-suspension method as modified and described by Moore (7) was used through-

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[3]Figures in parenthesis refer to "Literature Cited", p. 377.

out the tests at Manhattan, Kans. This method was used also at Denton, Tex., from 1938 to 1941. Since 1943 the inoculations at Denton have been made by the so-called "needle method" described by Shands and Schuller (10). Dry spores are introduced into the florets by means of a No. 20 hypodermic needle attached to the bulb of an eye-dropper. A mass of dry spores is placed in the bulb, after which a hypodermic needle is attached to it by means of a rubber band. The needle is inserted into the top of each floret, either by puncturing the lemma or by inserting it between the glumes. A very light pressure on the bulb forces a cloud of spores into the floret. In comparative tests, this method has given as good results as the vacuum method. Heads were prepared for inoculation by removing the less mature spikelets from the upper and lower portions of the spike and clipping the awns. At Urbana, Ill., all the inoculations were made in the field with a hypodermic needle and the spores suspended in a 1% dextrose solution, as described by Poehlman (9), with 1% malt extract added to the solution.

At Denton, the inoculum consisted of a composite of loose smut collected in nearby commercial wheat fields and in the wheat nursery at the Substation. At Manhattan, a similar composite from collections from various parts of Kansas was used. At Urbana, a composite of five collections, one each from South Carolina, North Carolina, Georgia, Texas, and Illinois, that had been the most virulent on differential varieties in physiologic race studies were used.

Four to eight spikes of each variety or strain, depending on the size of the spikes, were inoculated. At Denton, Tex., and Urbana, Ill., the seeds from the inoculated heads were bulked and then space planted for the test of that strain. At Manhattan, Kans., each head was kept separate and the seed planted in a separate 3-foot row from which separate counts of smut infection were obtained. These counts were then averaged for the reaction of the variety or strain. The number of plants grown each season of each variety or strain ranged from 50 to 150, averaging approximately 100.

EXPERIMENTAL DATA

Varieties and strains tested for their relative susceptibility or resistance to loose smut during the 7-year period, 1938–45, included all the hard and soft winter wheat varieties of commercial importance and many of the more promising unnamed hybrid selections. Included in the tests, also, were many varieties not grown commercially. Many strains were tested only one season or at only one location, but the varieties of greatest commercial importance or of promise as sources of resistance to loose smut were, in most instances, tested at two or more of the stations for several seasons. While the averages of the reactions of varieties are not completely comparable, because of the differences in the number of tests and some differences in inoculation technique, as well as in environment, they indicate the reactions of the varieties. The data on the reaction of varieties and strains are presented in Table 1 arranged in alphabetical order by kernel types. The classification of many hybrid strains is only tentative.

The data indicate that there are marked differences in the reaction of wheat varieties and strains to artificial inoculation with loose smut that must be attributed to relative resistance or susceptibility. While there was considerable variability in the results obtained from season to season the average infection percentage at each location is given. In each of the kernel type classes, there are some varieties that appear resistant to loose smut by their low infection percentage at one or more locations.

A total of 146 varieties and strains of hard red winter wheat have been tested at one or more of the stations. These include many strains that are not yet of commercial importance but are of special value at

one or more stations, or are included in regional tests in the hard red winter wheat Uniform Yield Nurseries. Some of these strains have not been tested sufficiently as yet to establish their true reaction to loose smut. Pawnee, which was developed from a cross of Kawvale×Tenmarq, was the only commercial hard red winter wheat variety that showed high resistance at all three stations. No infection was obtained in Pawnee in 7 years' testing at Denton, Tex.; only a trace in 5 years' testing at Manhattan, Kans.; and only 1% infection was obtained in the 1 year it was tested at Urbana, Ill., where the most virulent races of smut were used. A few other Kawvale×Tenmarq strains were highly resistant. A group of unnamed strains developed by the Kansas Experiment Station from the crosses Kawvale-Marquillo× Kawvale-Tenmarq and Marquillo-Tenmarq × Kawvale-Tenmarq showed high resistance at Manhattan, Kans. Many of these strains are also resistant to leaf and stem rust and to hessian fly, *Phytophaga destructor* (Say.), and offer promise of correlated resistance to certain important diseases and insect pests.

The unnamed strains, Kanred×Hope (C. I. 11976) and Hope× Turkey (C. I. 11964), are leaf and stem rust resistant strains, which showed low smut infection in two seasons at Denton, Tex. The South American strains Sinvalocho, Klein Triumfo, and Argentina I. F. Nos. 1050 and 1053 also had low infection percentages at Denton. A group of similar and, to some extent related varieties, namely Kanred, Nebraska 60, Nebred, Newturk, Tenmarq, and Ridit, were all highly susceptible at Denton, Tex., and Manhattan, Kans., but had low infection percentages at Urbana, Ill. This probably is due to different races present in the inoculum at the different locations.

Of the 117 soft red winter wheat varieties and strains tested only five were highly resistant at all three stations. The varieties Currell, Kawvale (semihard), Leap, Thorne, and Trumbull showed low or no infection at all stations and most strains were tested several seasons because of their known resistance and potential value as resistant parental material. The high resistance of Kawvale has been previously reported by Caldwell and Compton (3), Wingard and Fromme (12), Atkins (2), and in tests conducted in Russia by Artemoff (1). The resistance of Leap wheat was reported in 1926 by Fromme (6), and again in 1929 by Tapke (11). The resistance of Thorne and Trumbull was reported by Caldwell and Compton (3) in 1940. The varieties Ashland, Austin, Forward, Flint, Gipsy, Leap selection, Mannoth Red, Nured, Oakley, Valprize, Cornell 595, and several Mediterranean×Hope strains have zero or low infection readings at one or more stations where they were tested. The full value of many of these strains for use as breeding material cannot be determined until physiologic races of loose smut are more fully worked out and the analysis of genetic factors controlling the inheritance of resistance to them is determined. Some may be found to carry only one of several genetic factors for resistance while others may carry genetic factors controlling resistance only to certain races.

Many varieties reacted entirely different at the different stations indicating the presence of different physiologic races in the inoculum used. A number of varieties that are grown commercially in the major

TABLE 1.—*Loose smut infection obtained from artificial inoculation of winter wheat varieties and strains at Denton, Tex., Manhattan, Kans., and Urbana, Ill., in the years indicated.*

Class and variety or strain	State or F. P. I. No.*	C. I. No.	Denton, Tex., 1938–45		Manhattan, Kans., 1941–45		Urbana, Ill., 1943–45	
			Average infection, %	No. of years tested	Average infection, %	No. of years tested	Average infection, %	No. of years tested
Hard Red Winter								
Alton	—	1438	42	2	67	1	30	1
Argentina Inst. Fito. No. 1050	—	12085	0	1	—	—	—	—
Argentina Inst. Fito. No. 1051	—	12086	10	1	—	—	—	—
Argentina Inst. Fito. No. 1053	—	12088	0	1	—	—	—	—
Ashkof	—	6680	21	2	—	—	3	2
Bacska	—	6156	—	—	—	—	31	1
Beloglina	—	1543	—	—	—	—	23	2
Beloglina×Hussar	—	15513	30	2	—	—	—	—
Blackhull	—	6251	53	5	60	5	25	1
Blackhull selection	—	11737	36	2	—	—	—	—
Blackhull×Cheyenne	—	12101	0	1	—	—	—	—
Blackhull×Tenmarq	—	12102	30	2	—	—	—	—
Brill	—	11853	—	—	—	—	30	1
Cheyenne	—	8885	22	4	52	5	30	1
Cheyenne selection	—	11666	39	3	75	2	—	—
Cheyenne×Blackhull	—	12104	61	2	—	—	—	—
Cheyenne×Blackhull	—	12112	53	2	—	—	—	—
Cheyenne×Early Blackhull	—	11999	12	2	—	—	—	—
Cheyenne×Early Blackhull	—	12000	6	1	—	—	—	—
Cheyenne×Early Blackhull	—	12114	0	1	—	—	—	—
Cheyenne×Tenmarq	—	11972	76	3	71	4	—	—
Cheyenne×Tenmarq	—	11973	43	1	17	1	—	—

Cheyenne×Tenmarq	—	12103	—	—	86	4	—	—
Cheyenne×Tenmarq	—	12104	—	—	74	3	—	—
Cheyenne×Tenmarq	—	12123	—	—	26	4	—	—
Cheyenne×Tenmarq	Ks. 2759	—	—	—	79	3	—	—
Chiefkan	—	11754	42	4	66	5	0	1
Colorado No. 1143	—	11971	0	2	—	—	—	—
Comanche	—	11673	56	5	57	4	42	1
Coopertorka	—	8861	27	4	—	—	21	2
Eagle Chief	—	8868	—	—	46	5	24	2
Early Blackhull	—	8856	35	4	67	5	21	1
Early Blackhull Hybrid	—	11846	60	2	10	2	—	—
Early Blackhull×Tenmarq	Ks. 2756	—	—	—	57	2	—	—
Early Blackhull×Tenmarq	Ks. 2757	—	—	—	58	2	—	—
Early Blackhull×Tenmarq	Ks. 2769	—	—	—	73	1	—	—
Early Kanred	—	8261	12	4	—	—	—	—
El Milagro	F.P.I. 116015	—	0	1	—	—	—	—
Enid	—	11508	—	—	35	5	3	2
Fulhard	—	8257	8	1	9	5	—	—
Hope×Cheyenne	—	11969	24	4	—	—	—	—
Hope×Turkey	—	11964	8	2	—	—	—	—
Hope×Hussar	—	11682	—	—	—	—	Trace	1
Hope×Hussar	—	11834	—	—	—	—	7	1
Hussar	—	4843	39	3	44	5	46	3
Ilbred	—	8219	—	—	—	—	24	2
Iobred	—	6934	—	—	34	5	14	2
Iobred selection 2488	—	11998	—	—	70	2	—	—
Iobred selection 2473	—	11998	—	—	57	4	—	—
Iowa 404	—	5580	—	—	—	—	20	2
Iowin	—	10017	—	—	36	5	14	2
Ioturk	—	11388	—	—	43	4	14	1
Kanhull	—	11877	20	6	—	—	50	2
Kanred	—	5146	55	4	55	5	0	1
Kanred×Blackhull	—	11844	11	2	—	—	—	—
Kan.-Hard Fed. 142×Tenmarq	—	12105	50	1	70	3	—	—
Kan.-Hard Fed. 25007×Tenmarq	—	12106	76	1	—	—	—	—
Kan.-Hard Fed. 142×Tenmarq	—	12115	52	1	—	—	—	—

TABLE 1.—*Continued.*

Class and variety or strain	State or F. P. I. No.*	C. I. No.	Denton, Tex., 1938–45		Manhattan, Kans., 1941–45		Urbana, Ill., 1943–45	
			Average infection, %	No. of years tested	Average infection, %	No. of years tested	Average infection, %	No. of years tested
Kan.-Hard Fed. 254887 × Tenmarq	—	11974	82	1	—	—	—	—
Kan.-Hard Fed. × Minhardi-Minturki	—	11970	76	1	—	—	—	—
Kanred × Hope	—	11976	0	2	—	—	—	—
Kanred × Hope-Hard Federation	—	11975	11	3	—	—	—	—
Kanred × Marquis	—	11589	35	4	0	1	—	—
Kanred × Kanred-Marquis	—	11592	0	1	—	—	—	—
Kanred-Web.-Kanred × Hard Fed.-Marq.-Marq.	—	11977	75	1	—	—	—	—
Kanred × Quivira	Ks. 2763	—	—	—	52	3	—	—
Karmont	—	6700	—	—	—	—	21	2
Kawvale × Marquillo	Ks. 2848–4	—	4	1	—	—	—	—
Kawvale-Marquillo × Kawvale-Tenmarq	Ks. 2774–16	—	—	—	0	4	—	—
Kawvale-Marquillo × Kawvale-Tenmarq	Ks. 2775	—	—	—	Trace	4	—	—
Kawvale-Marquillo × Kawvale-Tenmarq	Ks. 2776	—	—	—	0	4	—	—
Kawvale-Marquillo × Kawvale-Tenmarq	Ks. 2777	—	—	—	0	3	—	—
Kawvale-Marquillo × Kawvale-Tenmarq	Ks. 2792	—	—	—	1	2	—	—
Kawvale-Marquillo × Kawvale-Tenmarq	Ks. 2793	—	—	—	Trace	3	—	—
Kawvale-Marquillo × Tenmarq	Ks. 2771	—	—	—	0	3	—	—
Kawvale × Tenmarq	—	11750	4	5	0	2	—	—
Kawvale × Tenmarq	—	11950	20	5	—	—	—	—
Kawvale × Tenmarq	—	11951	9	2	—	—	—	—
Kawvale × Tenmarq	—	11953	47	2	—	—	—	—
Kawvale × Tenmarq	—	11956	8	3	—	—	35	2
Kawvale × Tenmarq	—	11992	35	1	—	—	—	—

Kharkof	—	1442	40	6	44	5	15	2
Klein 47	F.P.I. 141358	12090	0	1	—	—	—	—
Litoral	F.P.I. 141359	—	6	2	—	—	—	—
Marmin	—	11502	—	—	13	3	28	1
Marquillo×Oro	—	11979	92	2	69	3	—	—
Marquillo×Oro	Ks. 790–1	11851	79	1	52	2	—	—
Marquillo×Oro	Ks. 787–1	—	35	1	—	—	—	—
Marquillo×Oro	Ks. 2760	—	—	—	28	1	—	—
Marquillo×Tenmarq	—	12113	61	1	78	3	—	—
Marquillo×Tenmarq	Ks. 2764	—	—	—	72	1	—	—
Marquillo×Tenmarq	Ks. 2765	—	—	—	74	1	—	—
Marquillo×Tenmarq	Ks. 2766	—	—	—	79	1	—	—
Marq.-Tenmarq×Kawvale-Tenmarq	Ks. 2773	—	—	—	0	1	—	—
Med.-Hope×Pawnee	Ks. 2788	—	—	—	54	1	—	—
Med.-Hope×Pawnee	Ks. 2789	12141	—	—	62	1	—	—
Med.-Hope×Pawnee	Ks. 2794	—	—	—	50	1	—	—
Michikof	—	6990	50	1	39	1	32	2
Minturki	—	6155	39	1	41	5	—	—
Minturki×Blackhull	—	11671	14	3	—	—	—	—
Minturki×Blackhull	—	11815	17	2	—	—	—	—
Montana 36	—	5549	—	—	—	—	27	2
Mosida	—	6688	60	2	35	4	45	2
Mutant, Colorado Selection	—	11660	Trace	4	—	—	—	—
Nebraska 60	—	6250	52	4	26	1	6	1
Nebred	—	10094	39	4	46	5	14	1
Newturk	—	6935	—	—	69	1	0	2
Oro	—	8220	45	4	29	5	18	1
Oro×Fulhard	—	11579	22	4	—	—	—	—
Oro×Tenmarq	—	11672	55	3	38	1	—	—
Oro×Turkey-Florence	—	11865	—	—	—	—	0	1
Pawnee	—	11669	0	7	Trace	5	1	1
Prelude×Kanred	—	11591	56	1	—	—	—	—
Purkof	—	8381	38	1	28	5	—	—
Quivira	—	8886	64	3	64	5	—	—
Quivira×Tenmarq	—	12166	62	1	27	3	—	—
Red Chief	—	12109	24	2	78	5	—	—

TABLE 1.—*Continued.*

Class and variety or strain	State or F. P. I. No.*	C. I. No.	Denton, Tex., 1938–45		Manhattan, Kans., 1941–45		Urbana, Ill., 1943–45	
			Average infection, %	No. of years tested	Average infection, %	No. of years tested	Average infection, %	No. of years tested
Redhull	—	11534	—	—	5	1	25	1
Regal	—	7364	—	—	—	—	30	1
Relief	—	10082	0	1	42	1	28	1
Relief×Ridit	—	11905	—	—	—	—	38	2
Ridit	—	6703	34	3	50	4	17	1
Rio	—	10061	—	—	—	—	36	2
Sherman	—	4430	—	—	—	—	48	1
Sibley 62	—	11523	29	2	48	5	32	2
Sibley 81	—	10084	—	—	31	5	—	—
Sinvalocho	—	12096	0	3	—	—	—	—
Tenmarq	—	6936	52	6	42	5	8	1
Tenmarq×Blackhull	—	12126	—	—	48	1	—	—
Tenmarq×Minturki	—	11580	74	3	—	—	—	—
Tenmarq×Nebr. 28	—	11847	60	2	—	—	—	—
Turkey	—	1558	85	1	46	5	26	1
Turkey selection	—	10016	24	2	35	1	—	—
Turkey selection	—	10083	59	3	—	—	—	—
Turkey selection	—	10098	—	—	23	3	—	—
Turkey selection	—	11530	43	1	18	3	32	1
Turkey selection	—	11576	6	1	—	—	—	—
Turkey selection	—	11577	26	3	11	1	—	—
Turkey selection	—	11667	15	3	—	—	—	—
Turkey selection	—	11734	50	1	—	—	—	—
Ukrainka	—	11935	—	—	59	1	33	1
Utah Kanred	—	11608	—	—	—	—	22	2

Westar	—	12110	44	2	—	—	—	—
Wichita	—	11952	66	4	58	4	—	—
Wisconsin Pedigree 2	—	6683	—	—	4	1	4	1
Yogo	—	8053	—	—	—	—	0	1
Soft Red Winter								
Ashland	—	6692	0	2	—	—	0	2
Austin	—	12346	0	3	—	—	—	—
Baldrock	—	11538	—	—	49	1	44	2
Berkeley Rock	—	8272	1	6	—	—	20	1
Carala	—	12184	—	—	—	—	26	1
Canawa	—	11854	—	—	—	—	61	1
China	—	180	21	2	—	—	41	1
Clarkan	—	8858	40	7	62	5	34	2
Climax	—	6302	—	—	—	—	17	1
Currell	—	3326	0	7	0	5	0	1
Denton	—	8265	55	7	6	4	0	1
Diehl-Mediterranean	—	1395	39	4	—	—	39	1
Early Premium	—	11858	0	7	0	4	28	3
Fairfield	—	12013	—	—	0	1	0	1
Flint	—	6307	0	3	—	—	6	1
Forward	—	6691	0	7	Trace	4	42	1
Fulcaster	—	6471	32	7	12	5	—	—
Fulcaster	—	4862	—	—	—	—	23	1
Fulcaster	W. Va. T-47-55	—	—	—	—	—	54	1
Fulhio	—	6999	0	1	0	4	16	2
Fultz	—	3416	95	7	—	—	—	—
Fultz	—	1923	—	—	6	5	9	2
Fultzo-Mediterranean	—	4811	—	—	—	—	19	2
Fultz-Hungarian	—	11850	—	—	—	—	40	1
Fultz-Hungarian	—	12017	—	—	—	—	Trace	1
Gasta	—	11398	0	4	0	1	16	1
Gipsy	—	3436	0	3	—	—	3	1
Gladden	—	5644	0	2	16	5	51	1
Goens	—	4857	75	2	—	—	30	1
Goldrop	—	6316	32	3	—	—	21	1

TABLE 1.—*Continued.*

Class and variety or strain	State or F. P. I. No.*	C. I. No.	Denton, Tex., 1938–45		Manhattan, Kans., 1941–45		Urbana, Ill., 1943–45	
			Average infection, %	No. of years tested	Average infection, %	No. of years tested	Average infection, %	No. of years tested
Golden Cross	—	5180	—	—	—	—	51	1
Grandprize	—	4876	—	—	—	—	5	1
Hardired	—	12183	—	—	48	3	28	1
Harvest Queen	—	6199	15	5	17	5	—	—
Harvest Queen×Kawvale	—	12284	—	—	10	3	—	—
Hungarian selection 1	—	4830	—	—	—	—	13	1
Hussar×Hohenheimer selection 1	—	10068	—	—	—	—	27	2
Illini Chief	—	5406	47	3	—	—	—	—
Illinois No. 2	—	11537	36	3	15	1	45	1
Imperial Amber	—	5538	64	3	—	—	67	1
Jones Fife	—	4468	23	6	3	5	53	1
Kawvale (semihard)	—	8180	3	7	Trace	5	0	3
Kay	—	12369	—	—	0	1	—	—
Kruse	—	11524	—	—	—	—	40	1
Leap	—	4823	0	7	0	4	0	3
Leap selection	—	12185	0	2	0	3	—	—
Leapland	—	11762	—	—	0	4	—	—
Lofthouse	—	3275	—	—	—	—	42	1
Mammoth Red	—	2008	—	—	0	1	0	1
Mealy	—	3358	90	1	—	—	18	2
Mediterranean	—	3332	—	—	44	5	10	1
Mediterranean	—	5303	—	—	—	—	0	1
Mediterranean selection 3015–01	—	10086	47	3	26	4	—	—
Mediterranean selection 3015–105–1	—	11587	35	3	—	—	—	—
Mediterranean selection 5933–20	—	10085	59	3	—	—	—	—

Mediterranean selection 5933–23	—	11525	39	2	—	—	—	—
Mediterranean selection 5933–38	—	—	63	3	—	—	—	—
Mediterranean×Hope	Tex. 41-8-5	11763	24	2	—	—	—	—
Mediterranean×Hope	Tex. 41-17-3	—	3	6	—	—	—	—
Mediterranean×Hope	Tex. 41-33-1	—	0	3	—	—	—	—
Mediterranean×Hope	Tex. 41-33-1-J13-4	—	0	5	—	—	—	—
Mediterranean×Hope	Tex. 41-33-1-J19-3	—	0	5	—	—	—	—
Mediterranean×Hope	Tex. 41-33-1-J19-4	—	0	5	—	—	—	—
Mediterranean×Hope	Tex. 41-206	—	0	5	—	—	—	—
Mediterranean×Hope	Tex. 41-C1394	—	0	5	—	—	—	—
Mediterranean×Hope	Tex. 41-C1730	—	0	5	—	—	—	—
Michigan Amber	—	—	—	—	—	—	23	1
Minhardi	—	5149	Trace	7	32	4	6	1
Nabob	—	8869	40	3	Trace	4	14	1
Newcaster	—	12472	—	—	—	—	10	1
Nigger	—	5366	14	2	—	—	19	1
Nittany	—	6962	0	3	0	4	40	1
Nured	—	—	0	4	—	—	—	—
Oakley	—	6301	0	3	—	—	7	1
Odessa	—	4475	31	2	—	—	42	1
Penquite selection	—	11745	20	4	89	1	—	—
Prairie	—	12069	35	2	71	4	44	2
Prairie selection	—	12371	—	—	—	—	47	1
Poole	—	3488	25	3	0	1	Trace	1
Portage	—	5654	50	3	—	—	62	1
Prosperity	—	5380	—	—	—	—	8	1
Purplestraw	—	1915	0	7	3	1	58	1
Purdue No. 1	—	11380	—	—	3	4	20	2
Purdue No. 4	—	11932	0	4	1	5	39	1
Purdue No. 7	—	12014	—	—	—	—	10	1
Red Chief	—	3392	8	2	—	—	—	—
Red Clawson	—	3393	—	—	—	—	79	1
Redhart	—	8898	9	3	—	—	23	1
Red Indian	—	8382	0	2	—	—	20	1
Red May	—	5536	83	1	24	5	38	1
Red May selection	Tex. 7250-1	—	67	7	—	—	—	—

TABLE 1.—*Concluded.*

Class and variety or strain	State or F. P. I. No.*	C. I. No.	Denton, Tex., 1938–45		Manhattan, Kans., 1941–45		Urbana, Ill., 1943–45	
			Average infection, %	No. of years tested	Average infection, %	No. of years tested	Average infection, %	No. of years tested
Red Rock	—	5597	33	3	4	4	30	1
Red Russian	—	4509	—	—	—	—	4	1
Red Wave	—	3500	17	2	52	1	22	1
Rice	—	5734	0	3	—	—	23	1
Rochester	—	—	—	—	—	—	7	1
Rudy	—	4873	33	2	—	—	34	2
Ruddy	—	6465	18	3	—	—	0	1
Rural New Yorker No. 6	—	5921	23	2	—	—	9	1
Russian	—	5737	74	3	—	—	42	1
Russian Red	—	5928	59	2	—	—	16	1
Shepherd	—	6163	53	5	—	—	28	1
Silversheaf	—	2496	—	—	—	—	0	1
Sol	—	6009	—	—	—	—	20	1
Thorne	—	11856	0	4	2	5	10	1
Triplet	—	5408	39	2	0	3	40	1
Trumbull	—	5657	0	6	0	4	9	2
Trumbull×Fultz	—	12217	0	3	—	—	—	—
Trumbull×Fultz	—	12220	8	3	—	—	—	—
Valley	—	5923	0	2	31	5	—	—
Valprize	—	11539	0	2	—	—	Trace	2
V.P.I. No. 112	—	11397	—	—	—	—	27	1
V.P.I. No. 131	—	10047	25	3	—	—	25	1
Wabash	—	11384	25	2	Trace	4	42	1
Walker	—	6445	20	3	—	—	18	2
Wheedling	—	4846	23	2	—	—	31	2
Zimmerman	—	2907	0	7	—	—	57	1

White								
American Banner	—	6943	—	—	23	4	28	2
Arco	—	8246	22	5	—	—	—	—
Cornell selection 595	—	—	0	2	—	—	—	—
Dawson	—	3342	24	4	—	—	—	—
Democrat	—	—	48	1	1	5	—	—
Galgalos	—	2398	17	2	—	—	—	—
Greeson	—	6320	1	3	—	—	—	—
Honor	—	6161	19	6	—	—	—	—
Kofod	—	4337	0	2	—	—	—	—
Longberry No. 1	—	5823	30	1	—	—	—	—
Martin	—	4636	—	—	42	1	—	—
Prohibition	—	4068	28	2	—	—	—	—
Pusa No. 114	F.P.I. 126807	—	60	2	—	—	—	—
Pusa No. 165	F.P.I. 126810	—	61	2	—	—	—	—
Rex	—	10065	—	—	51	3	—	—
White Odessa	—	4655	47	2	30	1	—	—
White Wonder	—	—	0	1	—	—	—	—
Yorkwin	—	11855	57	1	39	5	—	—
Club								
Albit	—	8275	—	—	36	2	—	—
Coppei	—	4238	31	2	—	—	—	—
Elgin	—	11755	—	—	2	2	—	—
Hybrid 128	—	4512	44	2	0	3	—	—
Hymar	—	11605	—	—	40	3	—	—
Jenkin	—	5177	—	—	60	2	—	—

*Ks. = Kansas; W. Va. = West Virginia; Tex. = Texas stations; F. P. I. = Accession number of the Division of Plant Exploration and Introduction (formerly Foreign Plant Introduction).

soft red winter wheat growing states were highly susceptible at Urbana, Ill., with inoculum used at that station, but were moderately to highly resistant at Manhattan, Kans., and completely free of smut through 7 years' tests at Denton, Tex. These varieties were Early Premium, Forward, Fulhio, Gasta, Gladden, Nittany, Purplestraw, Purdue No. 4 (C. I. 11932), Red Indian, and Zimmerman. In contrast, the varieties Denton, Mediterranean, Poole, and Fultz had low infection at Urbana and Manhattan, but were highly susceptible at Denton. The varieties Minhardi and Valley were highly susceptible at Manhattan, but only low infection percentages were obtained in them at Urbana and Denton. In contrast, the varieties Jones Fife, Red Rock, and Nabob were resistant at Manhattan, but susceptible at the other two locations. The varieties Blackhull, Harvest Queen, Fulcaster, and Russian were resistant in tests made by Tapke in 1929 (10), but susceptible at all three stations. The Indian varieties, Pusa Nos. 114 and 165, reported as resistant to loose smut in India (8), were highly susceptible to loose smut at Denton.

These data indicate clearly that inoculum used at the three stations was made up of races varying in their ability to attack the varieties tested. It emphasizes the need for care in the exchange of seed between wheat-growing areas. Races of loose smut may be carried to other areas in infected seed and later attack varieties previously considered resistant there.

SUMMARY

Two hundred and eighty-eight varieties and strains of winter wheat have been tested for resistance to loose smut by artificial inoculation in one or more years at one or more of the experiment stations at Denton, Tex., Manhattan, Kans., and Urbana, Ill. At the first two locations the tests were carried out under field conditions with bulk inoculum collected in nearby wheat-growing areas of each state, respectively, while at Urbana, collections from a wider area were used. Inoculation was effected with a hypodermic needle, using a water suspension of spores at Urbana. At Manhattan, the Moore vacuum spore suspension method was used. At Denton, the vaccuum method was used the first five seasons, but during the last two seasons a hypodermic needle attached to a rubber bulb was used to inject dry spores into the spikelet.

Pawnee is the only resistant variety of commercial hard red winter wheat available. The rust-resistant strains Kanred×Hope (C. I. 11976) and Hope×Turkey (C. I. 11964) showed low infection percentages at Denton, Tex., two seasons. Several Kawvale-Marquillo× Kawvale-Tenmarq strains were highly resistant at Manhattan, Kans., and offer considerable promise because they also are resistant to rusts and to hessian fly.

Among the soft red winter wheat varieties, the highest resistance was found in Currell, Kawvale (semihard), Leap, Thorne, and Trumbull. These varieties showed high resistance at all three locations. Many other varieties were resistant at one or more of the three stations and may offer possibilities as parental material resistant to certain races of loose smut. A number of Mediterranean×Hope strains,

resistant to leaf and stem rust as well as loose smut, are valuable for breeding work in the Texas area. These include the named variety Austin.

It is suggested that the most valuable parental material for breeding loose smut resistant varieties include the varieties Pawnee, Kawvale, Currell, Leap, Thorne, and Trumbull. The unnamed strains from the cross of Kawvale-Marquillo×Kawvale-Tenmarq appear of value because they combine resistance to loose smut with resistance to leaf and stem rust and to hessian fly. Likewise, the Kanred×Hope (C. I. 11976), Hope×Turkey (C. I. 11964), and the Mediterranean×Hope strains combine the Hope resistance to loose smut with good leaf and stem resistance. Differences in reaction of varieties at the several locations indicate physiologic race differences in the various inocula used. This suggests that caution should be used in the transfer of infected seed from one wheat-growing area to another to avoid the introduction of physiologic races not previously present there.

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Range Production as Related to Soil Moisture and Precipitation on the Northern Great Plains[1]

George A. Rogler and Howard J. Haas[2]

THE importance of proper rangeland management and control of range livestock numbers from year to year is well known to range men in the Northern Great Plains. The quantity of native grass varies greatly from year to year in this region, because of the wide fluctuation in precipitation. For this reason, many ranchers protect themselves against the unpredictable bad years by grazing moderately every year. This often results in a tremendous waste of grass in good years. It is obvious that a reliable method of predicting range production in advance of the grazing season would be of great value to ranchers. They could increase or decrease livestock numbers and manage their rangeland in accordance with the predicted amount of native grass for the coming season. In an attempt to develop a method of prediction, a study was made of the relationship of the amount of fall soil moisture to range production the following year at the Northern Great Plains Field Station, Mandan, N. D. The relationship of precipitation from April to July, inclusive, to current season production was also studied. Eighteen years data were available for studies of forage production as measured by hay yields. Nineteen years data were available for beef production as measured by gains.

REVIEW OF LITERATURE

Certain investigators have found a rather close relationship between the yields of both winter and spring wheat and the amount of soil moisture at seeding time.

Hallsted and Coles (4)[3] showed in their studies that there was a high correlation between the percentage soil moisture in the surface 3 feet at seeding time and the yield of winter wheat the following year. They suggested that the principal use of their data would be for the purpose of predicting crop failures. Among their conclusions was the statement that the smaller the quantity of stored moisture at seeding time, the more dependent the crop on the weather during the growing season and the greater the chances of a failure.

Hallsted and Mathews (5) studied yields of winter wheat and soil moisture data from three stations in central and western Kansas. They were able to show from their data that there was a close relationship between the depth to which the soil was wet in the fall at seeding time and the yield of winter wheat the following season. They were also able to show that the depth to which a given soil is wet is a reliable measure of the amount of available water in that soil.

Data from 15 stations in the Great Plains were used by Cole and Mathews (3) to show the relationship between the depth to which soil was wet at seeding time and the yield of spring wheat. They concluded that when the soil was wet only 1 foot or less seeding was not warranted because of the frequent failures. With

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[1]These investigations were conducted cooperatively by the U. S. Dept. of Agriculture, Agricultural Research Administration, Bureau of Plant Industry, Soils, and Agricultural Engineering, former Division of Dry Land Agriculture, and the North Dakota Agricultural Experiment Station, Fargo, N. D. Received for publication January 10, 1947.

[2]Agronomist, Division of Forage Crops and Diseases, and Associate Agronomist, Division of Soils, Fertilizers, and Irrigation, respectively. Mr. J. T. Sarvis was in charge of the project under which these investigations were carried on from 1915 to 1941, inclusive. The collection of most of the soil moisture data was under the supervision of Mr. J. C. Thysell.

[3]Figures in parenthesis refer to "Literature Cited", p. 388.

increases in the depth of moist soil, the margin of safety became greater. They concluded further that the highest assurance of good yields occurred when the soil was wet to a depth of 3 feet or more.

Cole and Mathews (2) discussed some of the soil moisture data that are used in this paper. The data they used were for the period 1916 to 1936, inclusive, which showed that sod removed water in the lower foot sections (3 to 6 feet) to a lower point in comparison with the wilting coefficient than did wheat. Their suggestion was that the lower foot sections under sod are lightly occupied by roots of deep-rooted perennial plants that do not remove the water rapidly in any one year, but because of their continuing draft are able to remove the water more completely than those of an annual crop.

Annual precipitation was shown by Cole (1) to have a high positive relationship to yield of spring wheat in the Great Plains. He pointed out that carryover of moisture in the soil from the previous year sometimes influenced yields to the point where they were markedly above the expected production based on total quantity of current year precipitation.

Pengra (6) studied the effect of precipitation on crop yields in central South Dakota. He divided the precipitation into a preseasonal period of August 1 to March 31 and a seasonal period of April 1 to July 31. The preseasonal precipitation was used as an estimate of the supply of moisture available in the soil at planting time. In the case of small grains, correlation coefficients for preseasonal precipitation and yields were larger than the corresponding coefficients for yields and seasonal precipitation. In the case of corn, the seasonal coefficient was much larger than that for preseasonal precipitation. He found in general that seasonal precipitation was rarely great enough to overcome a marked deficiency in soil moisture available at planting time.

Sarvis (7) described the investigations carried on from 1916 to 1940, inclusive, under the long-time grazing experiment of which the studies shown in the present paper are a part. He stated that because of the long growing season of the mixed native grasses and because of different levels of root development that soil moisture is more completely exhausted by native vegetation than by wheat. He found that early season precipitation (April, May, and June) exerts a greater influence on the production of native grasses than it does on such crops as wheat.

A press release from the U. S. Dept. of Agriculture summarized preliminary work done by Barnes in Wyoming on the relationship of fall soil moisture to next year's grass on the range.[4] It stated that this relationship was close and that studies were being continued to find a soil moisture figure that ranchers can use to predict the following year's range.

EXPERIMENTAL PROCEDURE

The area upon which these studies were conducted is located approximately 3.5 miles south of Mandan, N. D., and the soil is mainly Williams silt loam. It was in native sod of a mixed prairie type when acquired by the government for experimental purposes in 1915 and has remained in native sod since that time.

Data presented in this study dealing with the relationship of native forage yields to soil moisture and precipitation were obtained from a mowing experiment initiated in 1919. A typical mixed prairie climax type of vegetation grew on the area where forage yields were taken during the entire course of the experiment. The most important grasses of this mixed prairie association were *Bouteloua gracilis* (H. B. K.) Lag., *Stipa comata* Trin. and Rupr., and *Agropyron smithii* Rydb. *Stipa comata* made up the major portion of the harvested native forage from 1920 to 1933, inclusive. After the severe droughts of 1934 and 1936, *Agropyron smithii* replaced *Stipa comata* as the major component of the harvested forage.

For the purpose of studying the effect of fall soil moisture on the following season's forage yields, soil moisture data were used which were obtained in an undergrazed pasture adjacent to the mowing experiment. The vegetation in the undergrazed pasture was quite similar to that in the mowing experiment. Moisture equivalent determinations also showed the soil to be similar in the two locations. Soil moisture samples were taken at four points around a permanent quadrat 4 meters square.

[4]U.S.D.A. Press release CS-831–46 issued May 5, 1946.

The relationship of soil moisture and precipitation to cattle gains was determined on a 30-acre pasture that had been over-grazed each year since its establishment in 1916 as part of a long-time grazing experiment. Since approximately all forage on this over-grazed pasture was removed by grazing each year, gains per acre have been assumed to be a measure of the total forage production. Sarvis (7) gives a general description of the long-time experiment.

The vegetation in this over-grazed pasture rapidly changed after the start of the experiment to a short grass type consisting almost entirely of *Bouteloua gracilis*. For a number of years *Artemisia frigida* Willd., which is a deep-rooted unpalatable perennial weed, was very prevalent. This weed was reduced to a point where it was of no importance after these severe droughts of 1934 and 1936.

Soil moisture samples were obtained at four locations around a permanent quadrat 4 meters square located in the 30-acre over-grazed pasture. The soil moisture data obtained have been used in the present study to determine the effect of varying quantities of moisture in the fall on gains per acre the following season.

The dates of sampling for the years included in this study ranged from August 28 to November 6. In some years moisture determinations were not made in the fall. It was necessary therefore to eliminate these years from the study.

Moisture samples were taken in foot sections to a depth of 6 feet, with the standard soil tube. The soil was weighed, oven-dried at 100° to 110° C, and reweighed. Percentage moisture was determined on the dry weight basis. The percentage moisture was converted to inches of moisture in order that precipitation could be combined with soil moisture for study. In determining the inches of available water present in the soil, the minimum point of exhaustion was used instead of the wilting coefficient since plants will withdraw moisture to a point below the latter. The minimum point of exhaustion was determined for each foot section by averaging the inches of water in the soil at those times when it was considered that all of the moisture had been removed that the plants were capable of exhausting. The inches of available water in the fall were determined by subtracting the minimum point of exhaustion from the moisture present at the time of sampling. All further discussion of soil moisture in this article refers to available water only.

Precipitation was measured near the area where both forage yields and gains were obtained. In determining the effect of precipitation on forage yields and gains, data for the months of April through July only were used for the respective production years. It was found by the use of correlation coefficients that these were the months in which precipitation had the greatest influence on yields and gains.

RESULTS

Detailed data showing the years of study, precipitation from April to July, inclusive, of the production year, available moisture in the 3- and 6-foot depths of soil the preceding fall, forage yields, and cattle gains per acre are presented in Table 1.

FORAGE YIELDS AS RELATED TO MOISTURE

Soil moisture and yields.—Correlation and regression coefficients were determined for the purpose of showing the relationship between available fall soil moisture in the 3- and 6-foot depths and native forage yields the following season from data shown in Table 1. Highly significant coefficients of .72 and .74 were obtained for the correlation of forage yield and available soil moisture in the surface 3 feet and 6 feet, respectively. Scatter diagrams of yields and moisture are shown in Fig. 1. The line showing the regression of yield on available soil moisture is superimposed on the diagram concerned. The vertical distance of each dot from the line measures the error in calculating the yield from the available soil moisture by means of the regression equation.

TABLE 1.—*Precipitation from April to July, inclusive, available soil moisture, forage yields, and cattle gains per acre from 1918 to 1945, inclusive, Northern Great Plains Field Station, Mandan, N. D.*

Year	Precipitation April–July, incl., in.	Forage data			Gain data		
		Available soil moisture*		Forage yield per acre, lbs.	Available soil moisture*		Gain per acre, lbs.
		Surface 3 feet, in.	Surface 6 feet, in.		Surface 3 feet, in.	Surface 6 feet, in.	
1918	8.21	—	—	—	2.13	5.88	51.8
1920	6.54	0.69	3.61	238	0.19	2.31	58.7
1923	9.27	0.51	1.69	247	0.19	1.31	50.2
1924	8.95	1.04	1.91	652	1.02	1.88	81.5
1925	10.41	1.22	1.58	212	1.29	2.26	52.7
1026	6.41	0.57	1.42	29	0.51	1.52	24.8
1927	12.82	0.67	1.05	628	0.69	1.49	80.7
1928	12.08	2.95	3.68	278	3.01	3.82	56.7
1929	6.78	0.81	1.48	172	0.73	1.49	39.3
1930	6.94	0	0.20	137	0.02	0.59	28.5
1931	8.40	0.73	1.08	232	0.30	1.21	59.5
1932	10.20	0.23	0.52	630	0.14	1.04	68.8
1933	6.43	0.14	0.25	59	0.22	0.63	35.3
1934	5.23	0	0.18	37	0	0.10	12.2
1936	0.93	0.04	0.04	0	—	—	—
1941	13.00	1.71	2.04	421	1.48	1.86	101.9
1942	12.55	4.74	6.53	1,034	4.13	4.53	89.8
1943	13.11	3.14	6.42	998	2.90	5.04	118.8
1944	11.08	1.77	6.18	692	0.85	4.76	107.1
1945	6.36	—	—	—	1.65	5.27	113.4
Average..	8.79	1.16	2.21	372	1.13	2.47	64.8

*Soil moisture data collected the fall preceding the year shown.

Fig. 2 is a block chart giving the actual and estimated or expected forage yields based on the amount of available soil moisture the preceding fall for each year studied. It is apparent from a comparison of the actual and expected values that factors other than soil moisture had a pronounced effect on yields even though a highly significant positive relationship existed between the two variables. One of the most important factors influencing yields in addition to soil moisture was current season precipitation. For example, the actual yield in 1924 was much higher than the expected yield, due to a high June rainfall. In like manner, lower than average rainfall in some years resulted in actual yields lower than expected on the basis of the amount of soil moisture.

In order to place the measurement of soil moisture on a more practical basis, an attempt was made to convert inches of available water to feet of moist soil. Expressing the moisture in inches is more accurate, but is impractical for the rancher. No record was kept as to whether the soil at various depths felt dry or moist at the time of

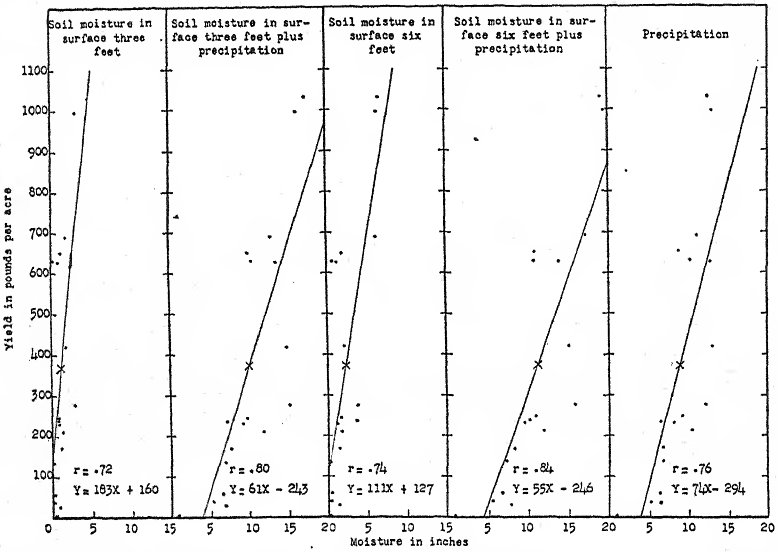

FIG. 1.—Diagrams showing the regression of native forage yields on available fall soil moisture in inches in two depths, on precipitation from April to July, inclusive, and on a combination of soil moisture and precipitation at Mandan, N. D.

sampling, thus it was necessary to compute the feet of moist soil from the inches of available water. Hallsted and Mathews (5) considered a foot section of soil to be moist when 0.5 inch or more of available moisture was present. This meant that the soil was not necessarily wet to field capacity to be considered moist. The moisture might be concentrated in a few inches of the foot section or distributed through-

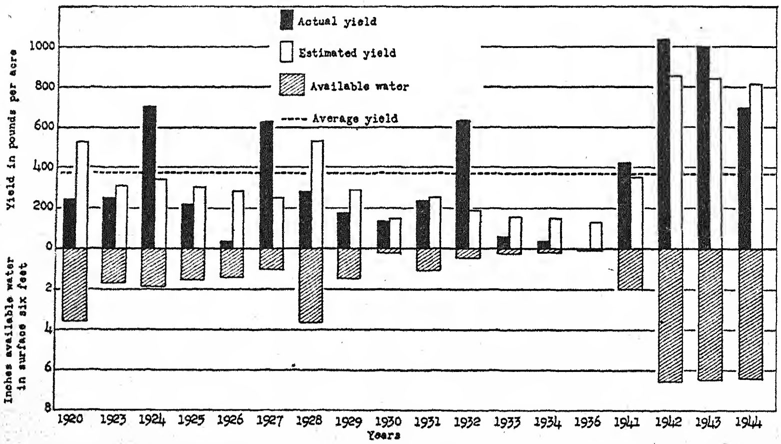

FIG. 2.—Actual and estimated native forage yields in pounds per acre and inches of available water in the surface 6 feet of soil the preceding fall at Mandan, N. D.

out. The above procedure was followed in the present study, that is, when less than 0.5 inch of available moisture was present in a foot section, it was considered dry. When 0.5 inch or more moisture was present it was considered moist. The soil in this study contained approximately 1.5 to 2.0 inches of available water per foot, depending upon the depth, when filled to capacity. In a few cases, dry layers of soil were found between moist layers. Since at least some of the roots were perennial, it was assumed that moisture at the lower depths was available to the plants in spite of the dry layer.

Table 2 shows the frequency of occurrence of designated yields of forage associated with a specified number of feet of moist soil in the surface 6 feet. It will be noted from the table that when the soil is dry in the fall, the chances of obtaining high yields the following season are small. As the number of feet of moist soil increases, the chance of obtaining high yields likewise increases.

It was found that the soil was dry to a depth of 6 feet in the fall 44% of the years studied. There was 1 foot of moist soil in 28% of the years and 3 feet or more of moist soil in 28% of the years. When the soil was dry, 88% of the yields were below 372 pounds per acre, which was the mean for the entire period. With 1 foot of moist soil only 40% of the yields were below the mean. Likewise, with 3 feet or more of moist soil, only 40% of the yields were below the mean. Although there was the same percentage of yields below the mean with either 1 foot or 3 feet or more of moist soil, Table 2 shows the average yield under the latter condition to be much higher. From these data it is evident that below average yields can be predicted fairly accurately when the soil is dry the preceding fall. With increasing quantities of moist soil in the fall, increasingly higher yields can be expected the following season on the average, but prediction is less accurate.

TABLE 2.—*Frequency of occurrence of designated yields of native forage per acre associated with specified quantities of moist soil in the surface 6 feet the preceding fall.*

Feet of moist soil in surface 6 feet	Forage yields in pounds per acre					
	199 or less	200 or more	400 or more	600 or more	800 or more	Average
None.........	6 in 8 or 75.0%	2 in 8 or 25.0%	1 in 8 or 12.5%	1 in 8 or 12.5%	0 in 8 or 0%	164
1 foot.........	0 in 5 or 0%	5 in 5 or 100.0%	3 in 5 or 60.0%	2 in 5 or 40.0%	0 in 5 or 0%	429
2 feet*........	——	——	——	——	——	——
3 feet or more..	0 in 5 or 0%	5 in 5 or 100.0%	3 in 5 or 60.0%	3 in 5 or 60.0%	2 in 5 or 40.0%	648

*There were no cases with only 2 feet of moist soil.

Precipitation and yields.—It is evident from the data in Table 1 that the amount of precipitation has a marked positive influence on native forage yields. A study was made of the effect of precipitation during

various periods on forage yields. The highest correlation coefficient (.76) was obtained when the precipitation for the period April to July, inclusive, was used. A scatter diagram and regression line of yields on precipitation for April to July, inclusive, is shown in Fig. 1. For the years in which forage yields were taken, the April-July precipitation was equal to or above the average of 8.95 inches 56% of the time. Seventy per cent of the yields for these years were above average. During 44% of the years the April–July precipitation was below average. In these years, the yields were below average 100% of the time.

Soil moisture plus precipitation, and yields.—In order to determine the effect of both fall soil moisture and precipitation on forage yields they were combined to give a single value for each year. Inches of available soil moisture in the surface 3 feet and surface 6 feet were each added to the April–July precipitation. A highly significant correlation coefficient of .80 was obtained for soil moisture in the surface 3 feet plus precipitation and forage yield. When the soil moisture in the surface 6 feet was added to the following April–July precipitation, an even higher coefficient of .84 was obtained.

Scatter diagrams and regression lines shown in Fig. 1 for yields and for soil moisture and precipitation added together, show a high positive relationship between yields and the combined moisture value. The "goodness of fit" of regression lines for yield on soil moisture both at 3-foot and 6-foot depth plus precipitation was considerably better than when soil moisture and precipitation were considered separately.

It is evident that the value obtained, where soil moisture was added to precipitation, could not be used for prediction purposes. Nevertheless, it is apparent from the data that the two most important variables determining yield are the amounts of soil moisture the preceding fall and current season precipitation.

CATTLE GAINS AS RELATED TO MOISTURE

Studies were made of the effect of varying quantities of soil moisture and precipitation on cattle gains. These studies were similar to those discussed above. Since the animal variable was brought into the study in addition to the variables of soil moisture and precipitation, it was not expected that as high positive relationships would be obtained for gains and soil moisture or precipitation as were obtained for those variables and forage yield.

Soil moisture and gains.—Correlation and regression coefficients were determined from the data presented in Table 1 for the soil moisture in the 3-and 6-foot depths and gains in pounds per acre the following season. The correlation coefficients for gains and soil moisture in the 3-foot and 6-foot depths were .52 (significant) and .64 (highly significant), respectively. Regression lines were superimposed on scatter diagrams of gains and moisture shown in Fig. 3. It is apparent that there was a positive relationship between soil moisture and gains, but the "goodness of fit" of the regression lines in both the diagram of the 3-foot and 6-foot depths was not high.

Fig. 4 is a block chart giving the actual and estimated or expected gains based on the amount of available soil moisture in the surface 6 feet. The chart shows considerable discrepancy between expected and actual gains in some years. These discrepancies existed because

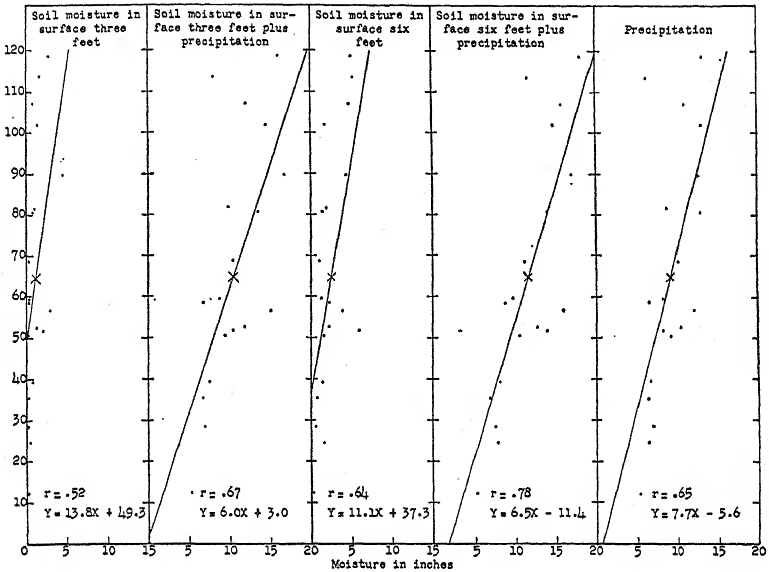

FIG. 3.—Diagrams showing the regression of cattle gains on available fall soil moisture in inches in two depths, on precipitation from April to July, inclusive, and on a combination of soil moisture and precipitation at Mandan, N. D.

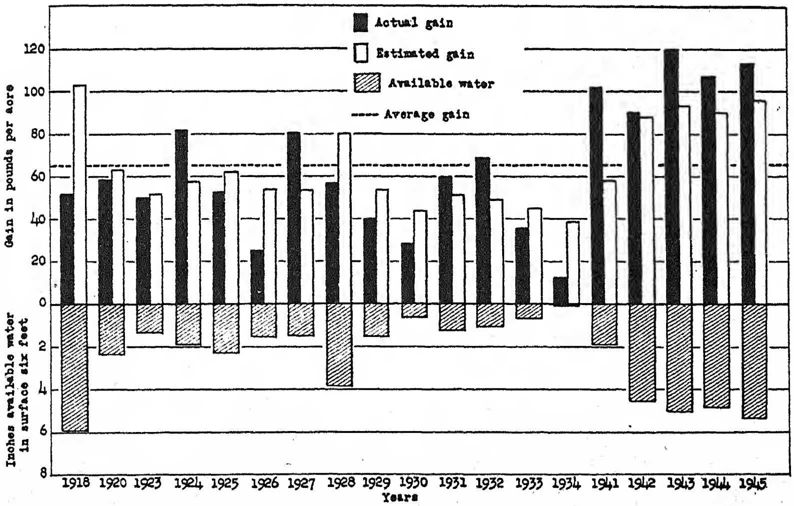

FIG. 4.—Actual and estimated cattle gains in pounds per acre and inches of available water in the surface 6 feet of soil the preceding fall at Mandan, N. D.

factors other than the amount of soil moisture had a marked influence on gains. Some of these factors may have been the poor or good distribution of rainfall which would influence the continuous production of nutritious grass, high or low seasonal temperatures which have a direct influence on cattle gains, and the condition of the cattle themselves. Thin and thrifty cattle would make more rapid gains, at least at the start of the season, than those carrying more flesh.

The available soil moisture in the surface 6 feet of the pasture in which gains were taken was converted to the number of feet of moist soil as described under the heading "Forage Yields as Related to Moisture". Table 3 shows the frequency of occurrence of designated gains per acre associated with a specified number of feet of moist soil in the surface 6 feet. It is evident from the data presented in this table that when the soil is dry in the fall, chances of obtaining high gains the following season are small. With an increasing number of feet of moist soil the chance of obtaining high gains also increases. It was found that the soil was dry to a depth of 6 feet in the fall during 42% of the years studied. Twenty-one per cent of the time there was 1 foot of moist soil and 37% of the time there were 3 feet or more of moist soil. When the soil was dry, 88% of the seasonal gains per acre were below 64.8 pounds which was the average for the entire period. With 1 foot of moist soil only 25% of the gains were below average. Forty-three per cent of the gains were below average when there were 3 feet or more of moist soil. Even though there were more gains below average with 3 feet or more of moist soil than with 1 foot, Table 3 shows the average of these gains to be much higher than those when there was 1 foot of moist soil.

TABLE 3.—*Frequency of occurrence of designated cattle gains per acre associated with specified quantities of moist soil in the surface 6 feet the preceding fall.*

Feet of moist soil in surface 6 feet	Gains in pounds per acre						
	19.9 or less	20 or more	40 or more	60 or more	80 or more	100 or more	Average
None.......	1 in 8 or 12.5%	7 in 8 or 87.5%	3 in 8 or 37.5%	1 in 8 or 12.5%	0 in 8 or 0%	0 in 8 or 0%	39.8
1 foot......	0 in 4 or 0%	4 in 4 or 100.0%	4 in 4 or 100.0%	3 in 4 or 75.0%	3 in 4 or 75.0%	1 in 4 or 25.0%	79.2
2 feet*.....	—	—	—	—	—	—	
3 feet or more	0 in 7 or 0%	7 in 7 or 100.0%	7 in 7 or 100.0%	4 in 7 or 57.1%	4 in 7 or 57.1%	3 in 7 or 42.9%	85.2

*There were no cases with only 2 feet of moist soil.

Precipitation and gains.—Fig. 3 shows a scatter diagram and regression line of gains per acre on April–July precipitation. This diagram was constructed from data shown in Table 1. The correlation coefficient of .65 for the relationship of gains and precipitation was highly significant. The "fit" of the regression line was not as good as

that of the line for forage yield on precipitation shown in Fig. 1 because of the greater number of factors influencing cattle gains. The April–July precipitation for the years used in studying gains was above the average of 9.20 inches 47% of the time. With this amount of precipitation, gains per acre were above the average of 64.8 pounds 67% of the time. Fifty-three per cent of the time the April–July precipitation was below average. Under these conditions, 80% of the gains were below average.

Soil moisture plus precipitation and gains.—In order to determine the relationship of both soil moisture and precipitation to gains per acre, the available inches of soil moisture in the surface 3 feet and surface 6 feet were added to the April–July precipitation for each year. Correlation coefficients were determined for these values and gains. Scatter diagrams and regression lines are shown in Fig. 3. A highly significant coefficient of .67 was obtained for the correlation of gains and soil moisture in the surface 3 feet plus April–July precipitation. A highly significant coefficient of .78 was also obtained for gains and soil moisture in the surface 6 feet plus April–July precipitation.

It is apparent from a study of the regression line for gains per acre on soil moisture in the surface 6 feet plus precipitation that expected values came closer to actual values than for any other variables considered in relation to gains.

DISCUSSION

There might be some question whether seasonal gains per acre or seasonal gains per head would be more logical to use in a study of the relationship of soil moisture and precipitation and gains. For the purpose of this paper, gains per acre were used because this gain factor seemed to describe most fully the total forage production. Actually, the results would have been quite similar if gain per head instead of gain per acre had been used. This is indicated by an extremely high correlation coefficient of .95 for seasonal gain per head and seasonal gain per acre as determined from the data obtained on the overgrazed pasture for the years covered in the study.

It is obvious that the prediction of gains would be of more value to ranchers than the prediction of forage yields. Since a correlation coefficient of .83 was obtained for forage yields and gains per acre, the data presented in this paper on soil moisture and forage yields are also of value in relation to soil moisture as effecting gains.

An attempt was made to predict actual intensities of grazing that could be used the following season when there was a certain amount of soil moisture in the fall. The gain data used were taken from a number of pastures grazed at various intensities. A trend was evident showing that heavier intensities of grazing could profitably be used when there were increasing amounts of soil moisture. It was impossible, however, because of the limited amount of data, to predict even within fairly wide limits the proper grazing intensities based on the amount of fall soil moisture.

The data presented here may be of considerable value in forecasting range production within certain limits. They are principally of value

in predicting chances of low range production ahead of the season. The smaller the quantity of soil moisture or the less depth of moist soil in the fall, the more likely the native forage production will be low the coming season.

SUMMARY

This study was made to determine the relationship of the amount of soil moisture the preceding fall and current season April–July precipitation to native forage yields and gains per acre.

The data showed highly significant correlation coefficients of .72 and .74 for the amount of fall soil moisture in the surface 3 feet and surface 6 feet, respectively, and native forage production the following season.

When soil moisture was above or below average, forage yields also showed a positive relationship of being above or below average. On the area where forage yields were taken the soil was dry to a depth of 6 feet 44% of the time. When dry, 88% of the yields were below average. Increasing depths of moist soil produced, in general, increasingly higher yields of hay the following season.

A highly significant correlation coefficient of .76 was obtained for April–July precipitation and yield the same season. Above average April–July precipitation was accompanied with above average yields 70% of the time. When the precipitation was below average, yields were below average 100% of the time.

By adding the amount of soil moisture to the April–July precipitation a higher positive relationship was obtained for this value and yields than when either soil moisture or precipitation were used separately.

There was a positive relationship between soil moisture and gains, but it was not as high as that for forage yields because of the additional variation brought in by the animal unit.

On the area where gains were measured the soil was dry to a depth of 6 feet 42% of the time. When dry, 88% of the gains were below average. As in the case of forage yields, increasing depths of soil moisture produced, in general, increasingly higher gains.

A highly significant correlation coefficient of .65 was obtained for April–July precipitation and gain. Above average April–July precipitation was accompanied by above average gains during 67% of the time. When the precipitation was below average, 80% of the gains were below average.

When the amount of soil moisture in the fall was added to the April–July precipitation, a higher positive relationship was obtained for this value and gains than when either soil moisture or precipitation was considered alone in relation to gains.

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The Effect of Various Fertilizers on the Botanical Composition and Yield of Grass-Legume Hay[1]

A. E. Rich and T. E. Odland[2]

RESEARCH was begun at the Rhode Island Experiment Station in 1911 to determine the relative efficiency of various fertilizer materials as carriers of potash (3, 4, 5, 8).[3] Workers at other stations in the northeast also have done considerable work on fertilizing haylands.

Lyon and Bizzell (7) reported that under New York conditions timothy responded to nitrogen, potash, and phosphorus in that order. They found that alfalfa yields were increased more by the application of 5 tons of manure than by a very light topdressing of superphosphate (200 pounds) and muriate of potash (32 pounds).

Brown (2), in Connecticut, reported that nitrogen, especially that in manure, increased yields but reduced the amount of alfalfa. Phosphorus increased the amount of alfalfa. Potassium, either in manure or muriate of potash, was very beneficial but the chemical form was preferred.

Beaumont, *et al.* (1) found nitrogen and potash more important than phosphorus for increasing the longevity of hayfields in Massachusetts. A 3:1:2 fertilizer ratio was recommended.

Prince, *et al.* (9, 10) found that in New Hampshire potassium was the most important element for prolonging the stand and increasing the yield of alfalfa.

DESCRIPTION AND RESULTS OF EXPERIMENT

The purpose of the original experiment was not only to test the efficiency of several sources of potash, but also to determine the effect, if any, of the other ingredients, i. e., sodium, magnesium, and chlorine, on yields. Therefore, carriers of nitrogen and phosphorus were chosen which were low in sodium, magnesium, and chlorine.

Six plots (114 to 119, inclusive) 2/15 acre in size were used for this study. The soil is classified as Bridgehampton very fine sandy loam. The land is practically level and the soil very uniform.

The potash carriers selected for trial were kainite, muriate of potash, sulfate of potash, and double sulfate of potash-magnesia. One plot (116) received no potassium, another (119) received what was considered an optimum amount, while the other plots received sub-optimum amounts of potassium.

During the first 7 years of the experiment there was apparently no potassium deficiency on any plot. At the end of 16 years, however, the yields on the plot which received no potash were so low that the plans were changed to include a small application of potash there also.

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[2]Assistant Agronomist and Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 394.

No single source of potash proved superior for all crops or for any one crop every year. The sodium in the kainite was a parital substitute for potassium. The magnesium in the double sulfate of potash-magnesia apparently had no beneficial effect.

A hay mixture, largely legumes, was grown on these plots in 1924 and 1925. The high-potash plot averaged 4.26 tons per acre while the low-potash plot produced only 1.34 tons per acre. The kainite plot averaged approximately ½ ton per acre more than the other plots which received the same amount of potash. These results do not agree with those of Haskell (6), who reported that kainite produced smaller yields than the other potash carriers, probably due to the high concentration of soluble salts in kainite.

A timothy-redtop mixture was grown on these same plots in 1929, 1932, and 1933. The high-potash plot produced about ½ ton more per acre (2.52 tons) and the low-potash plot about ½ ton less per acre (1.58 tons) than the other plots. The larger difference in yield between treatments for the legumes than for grasses indicates that less potash is required by grasses than by legumes.

Eight more plots (120 to 127, inclusive) were added to this experiment in 1930 in order to compare different levels of nitrogen and phosphorus fertilization as well as potassium.

The use of kainite and double sulfate of potash-magnesia was discontinued in 1935, as they are usually uneconomical sources of potash.

The plots have remained in hay for only one or two years at a time, although both leguminous and nonleguminous hay has previously been grown on them. Therefore, the effect of fertilization on the longevity of stand of the various legumes and grasses, or its effect on yields over a period of years has not been studied until recently. In order to study these effects, in the spring of 1941 a legume-grass mixture was seeded with oats as a companion crop. The composition of the seeding mixture was as follows, expressed in pounds per acre: Grimm alfalfa, 7 pounds; medium red clover, 5 pounds; alsike clover, 3 pounds; timothy, 3 pounds; and redtop, 2 pounds.

The annual fertilizer treatments, hay yields and average botanical composition on plots 120 to 127, inclusive, are presented in Table 1.

TABLE 1.—*The effect of varying amounts of nitrogen and phosphorus on the yield and average estimated composition of legume-grass hay, 1941–1945, inclusive.*

Plot No.	Treatment, $N-P_2O_5-K_2O$	Yield in tons per acre*						Average per cent	
		1941	1942	1943	1944	1945	Average	Legumes	Grasses
123	10–80 –100	3.87	3.58	4.18	3.71	3.40	3.75	74	26
127	10–80 –100	3.44	3.35	3.55	3.02	3.29	3.33	65	35
121	5–80 –100	3.74	3.32	3.36	2.81	4.08	3.46	62	38
125	5–80 –100	3.55	3.20	3.82	3.16	3.41	3.43	73	27
122	20–40 –100	4.04	3.18	3.99	3.05	3.78	3.61	60	40
126	20–40 –100	4.11	3.53	3.68	3.19	4.02	3.71	63	37
120	20–20 –100	3.21	3.65	3.79	2.72	4.13	3.50	59	41
124	20–20 –100	4.15	3.40	4.05	3.29	3.26	3.63	74	26

*15% moisture basis.

These results show that reducing the amount of nitrogen had very little, if any, influence on either the yield or composition of the hay. (Reducing the amount of P_2O_5 to as low as 20 pounds on plots 120 and 124 apparently did not influence the yield or botanical composition of the hay.)

The results of fertilizer treatments on plots 114 to 119 for the period 1911–1940 have been published previously (5, 8). These plots received 20 pounds of nitrogen and 80 pounds of P_2O_5 annually from 1941–1945, inclusive. The annual fertilizer treatments, hay yields, and average estimated botanical composition for each plot are presented in Table 2.

TABLE 2.—*The effect of varying amounts of potash on the yield and average estimated composition of legume-grass hay, 1941–1945, inclusive.*

Plot No.	Treatment, $N\text{-}P_2O_5\text{-}K_2O$	Yield in tons per acre*						Average per cent	
		1941	1942	1943	1944	1945	Average	Legumes	Grasses
118	20–80 –100 M†	3.62	2.46	3.21	2.27	3.20	2.95	49	51
114	20–80 –100 S	3.75	5.58	3.51	2.62	3.47	3.79	57	43
119	20–80 –100 S	3.56	3.01	1.94	1.56	2.42	2.50	35	65
115	20–80 –50 M	3.24	2.66	1.28	0.79	1.11	1.82	3	97
117	20–80 –50 S	2.35	2.08	1.19	0.67	0.93	1.44	3	97
116	20–80 –25 M	2.11	1.82	0.79	0.54	0.61	1.17	2	98

*15% moisture basis.
†M = Muriate of potash; S = sulfate of potash.

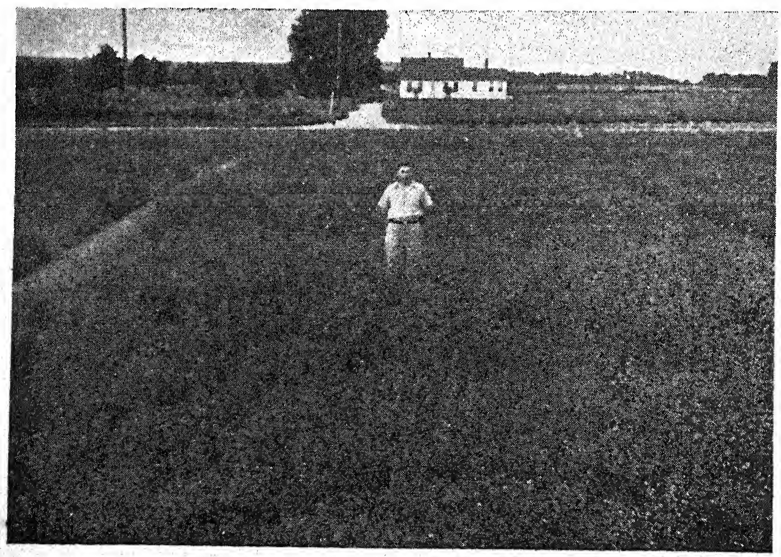

FIG. 1.—Plot 119, July 17, 1944. Fertilizer 20 pounds N, 80 pounds P_2O_5, and 100 pounds K_2O annually. Good stand of legumes 4 years after seeding.

It will be noted that plot 114 produced the heaviest yields (3.79 tons per acre) and also had the highest percentage of legumes (57%). These increased yields may have been due to the residual effect of sodium from kainite applied from 1911–1934, inclusive, or to minor elements present in the kainite.

On the other hand, plot 119 produced the lowest yield of any of the plots receiving an equivalent amount of potash (2.50 tons per acre) as well as having the lowest percentage of legumes (35%). Possibly the large crops removed from this plot in past years have depleted one or more of the minor elements to such an extent that their deficiency has become a limiting factor. Previously it always had been a very high-yielding plot.

Reducing the application of K_2O from 100 pounds to 50 pounds lowered the proportion of legumes in the stand from an estimated 35% or more (Fig. 1) to 3% (Fig. 2). The average yields were also reduced from 3.08 tons (plots 114, 118, 119) to 1.63 tons (plots 115 and 117) per acre. A further reduction in potash to 25 pounds lowered the proportion of legumes to 2% (Fig. 3) and the yield of hay to 1.17 tons.

SUMMARY

A legume-grass mixture was seeded on a series of 14 plots in the spring of 1941. Varying amounts of nitrogen, phosphoric acid, and potash were applied to study their effect on the botanical composition and yield of the hay crop. The standard application was 20 pounds nitrogen, 80 pounds phosphoric acid, and 100 pounds potash per acre annually as a topdressing. Reducing the nitrogen or the phosphoric acid had no significant effect on either the yield or the percentage of legumes in the hay. Reducing the potash from 100 to 50 pounds

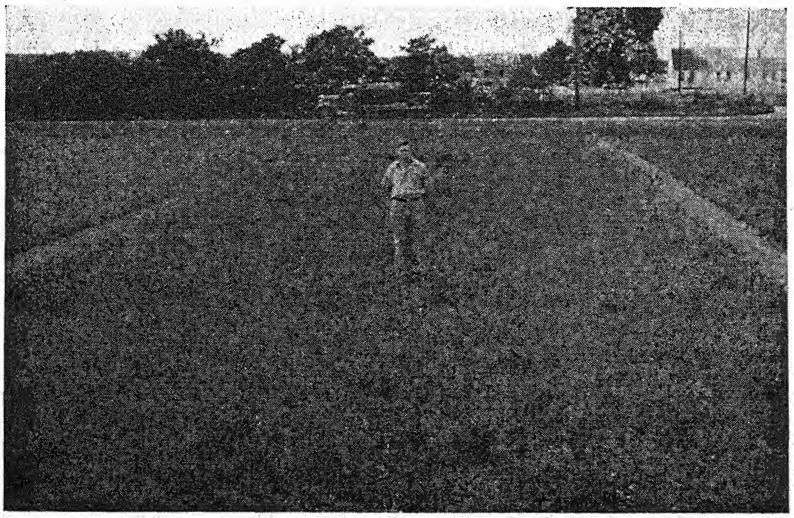

FIG. 2.—Plot 117, July 17, 1944. Fertilizer 20 pounds N, 80 pounds P_2O_5, and 50 pounds K_2O annually. Poor stand of legumes.

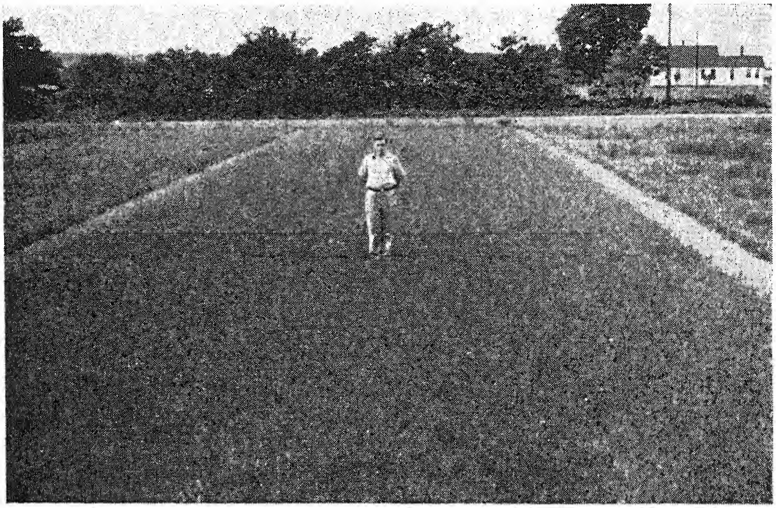

FIG. 3.—Plot 116, July 17, 1944. Fertilizer 20 pounds N, 80 pounds P_2O_5, and 25 pounds K_2O annually. No legumes.

lowered the proportion of legumes from 50 to 3% and the hay yield from 3.08 to 1.63 tons per acre. A further reduction in potash to 25 pounds resulted in less than 2% legumes and a hay yield of only 1.17 tons per acre.

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Studies on the Chemical Control of Rice Weeds[1]

T. C. RYKER[2]

RICE is the second agricultural crop in importance in Louisiana, being grown on about half a million acres. The greater part of the rice acreage is in the southwest prairie area of the state, but some rice is grown in the Bayou Teche and the lower Mississippi River sections in areas where it is possible to flood the fields.

The primary purpose of the early flooding of rice is to control grass and other weeds. The usual practice is to drill the seed in a well-prepared seedbed and then to flood 10 to 20 days after the seedlings emerge. The initial water is held 2 to 6 inches deep and this usually drowns out the greater part of the weeds that are smaller than the rice. While flooding is generally effective in controlling weeds, in certain areas and under certain conditions other measures must also be used. Frequently rain follows closely on planting and weeds get such a start that the water will not control them.

The most important weeds other than grasses are indigo, *Sesbania macrocarpa Muhl.*, curly or frizzly indigo, *Aeschynomene virginica* (L) B.S.P., and Mexican weed or birdeye, *Caperonia castaneaefolia* (L) St. Hil. There are a number of other broad-leaf weeds that are of less importance, some of which do not grow in water but are troublesome when growing on the levees. Indigo and curly indigo can be controlled by hand pulling, but this costs from $1 to $10 per acre and is dependent upon a relatively cheap source of labor. Mexican weed, on the other hand, cannot be pulled economically. In some instances the rice and weeds are mowed. This injures the rice but not to the extent that the weeds would if left in the field. The losses to the Louisiana rice farmer caused by weeds is difficult to estimate, but it probably is well over a million dollars annually.

Chemicals for weed control have been sought for a long time, but it is only in recent years that much progress has been made in the development and use of differential herbicides. Sinox, a contact herbicide, introduced to this country in 1938,[3] has been found useful under some conditions. The real impetus to the chemical control of weeds came with the discovery[4] that certain of the hormone-like chemicals, such as 2,4-D (2,4-dichlorophenoxy-acetic acid), when used at relatively low concentrations, kill certain broad-leaf plants without materially injuring some of the cereals and other grasses.

The purpose of the present investigations was to determine the feasibility of using selective herbicides in the control of certain rice weeds. Following a preliminary test in 1945, a rather large number of

[1]Contribution from the Louisiana Agricultural Experiment Station, Baton Rouge, La. Received for publication January 25, 1947.

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[3]ROBBINS, W. W., CRAFTS, A. S., and RAYNOR, R. N. Weed Control. New York: McGraw-Hill Book Co., Inc. 1942.

[4]HAMNER, C. L., and TUKEY, H. B. Selective herbicidal action of mid-summer and fall applications of 2,4-dichlorophenoxyacetic acid. Bot. Gaz., 106:233–245. 1944.

tests were made in 1946 with both Sinox and 2,4–D under different field conditions. This paper presents the results.

It is interesting to note that the farmers of the rice area were so enthusiastic over the results of the early tests that they airplane dusted over 3,000 acres with 2,4–D later in the season.

MATERIALS AND METHODS

In the tests made paired plots approximately 1/50th acre in size (20 × 44 feet) with one exception were used. They were selected as far as possible for uniformity of soil and weed infestation. Sinox and the sodium salt of 2,4-D, or the acid plus sodium carbonate, were the principal materials used. They were applied either as a spray with a knap-sack sprayer at the rate of 100 gallons per acre, or as a dust with a hand duster at approximately 20 pounds per acre. The 2,4-D was used at a concentration of 1,000 p.p.m. and the Sinox at the rate of 1 gallon plus 1.6 pounds of ammonium sulfate to 80 gallons of water. In several tests dusts were used and included 2,4-D of a 10% acid content or 15% Sinox.

The effectiveness of the herbicides was determined from weed counts and yields of rice. Weed counts were made 6 to 8 weeks after treatment by dropping a 1 foot square frame at nine fixed points over the plots and counting all weeds within the frame. Where weed populations were small all weeds in the plot were counted. Yields were obtained by cutting two 3½ × 12 foot samples in each plot. These were dried, threshed, and yields computed in bushels (45 pounds) per acre. As far as possible, the same drill rows were included in the samples taken from the treated and untreated plots. In most instances where indigo and curly indigo occurred in the plots they were removed by the grower before they had damaged the rice, and so the actual effect of the herbicide treatments do not show fully in the yields obtained.

RESULTS

EFFECT OF SINOX AND 2,4–D ON RICE

In some preliminary tests made in the greenhouse, Q. L. Holdeman observed that Sinox injured rice slightly. The margins and tips of the leaves showed some burning, but they seemed to recover quite rapidly. On the other hand, the 2,4–D at first slowed down the growth of the plants, but as they recovered the foliage seemed to turn darker green.

To obtain more information on the effect of 2,4–D on rice in the absence of weeds, a test was made on Magnolia rice at the Rice Experiment Station at Crowley, La. Plots 10 x 43 feet were laid off in a field in which there were very few weeds. The first plot was sprayed May 7, 3 days previous to flooding or about 4 weeks after planting. The other plots were sprayed at various dates until after the plants headed. Every third plot was left untreated to serve as a control. This left a control plot next to each treated plot. A spray concentration of 1,000 p.p.m. was used in the tests up to and including June 12, and was doubled in the treatments made thereafter. The time of the various treatments and the yields of the plots are shown in Table 1.

The results indicate that 2,4–D applied at certain periods in the development of the plants may reduce the yield of rice. While the plots were not replicated, the results indicate that the yields were reduced in the plots sprayed before flooding and in those sprayed after the rice had headed. Plants sprayed May 7, prior to flooding, became stunted (Fig. 1), and turned a dark green. The base of the plants became swollen and the new emerging roots remained short and

TABLE 1.—*Effect of 2,4-D on the yield of Magnolia rice treated at various stages of growth in 1946.*

Time of treatment	Stage of development	Plant yield in bu. per acre		Difference in bu. in acre	Remarks
		Control	Treated		
May 7	Preflood	72.7	56.9	−15.8	Stunting
May 22		67.7	70.2	+ 2.5	
May 29		67.7	53.3	−14.4	
June 3		60.8	75.2	+14.4	
June 12		60.8	66.2	+ 5.4	
June 26	Preboot	66.6	60.5	− 6.1	
July 9	Booting to heading	66.6	50.8	−15.8	Slight blasting
July 24	Heading	66.2	38.2	−28.0	Considerable blasting

stubby for about 1 week. The plants recovered to a large degree within 2 weeks following treatment and appeared to grow normally thereafter, but they retained the darker green color throughout the season and tillered somewhat less. The tests were complicated by the fact that the entire planting developed root-rot about the time that the plants in the first treatment were beginning to recover. The water was drained from the field at this time and this checked the root-rot, but still the plants in the earliest sprayed plot did not recover like plants recovered in other fields where root-rot was not present. The marked lag in growth in the plot treated before flooding was probably due largely to the fact that 2,4-D induced a temporary lag in root development at the critical time that the plant was shifting over from the initial dry-land to a submerged condition. Treatments made after flooding induced some swelling of the base of the plants and a darkening in color but did not result in stunting. Plants sprayed at flowering time showed considerable blasting of the florets. In severely affected florets the hulls remained open, were discolored, and in some instances the grains were poorly developed. Panicles treated after flowering showed a brownish discoloration and in many instances further development of the grain was inhibited. There was also some bending of the stems at the upper nodes.

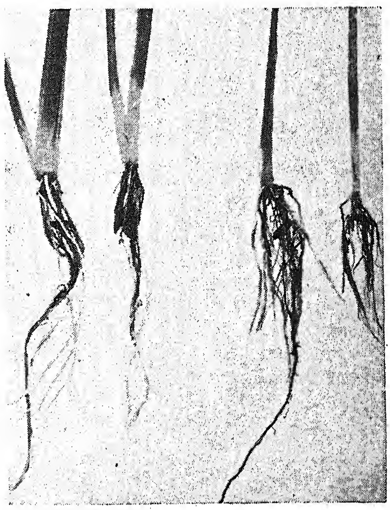

FIG. 1.—The effect of 2,-4,D on Magnolia rice treated before flooding. Plants on right 17 days after treatment showing the normal development of new roots at this time. Plants on left untreated. Two-thirds natural size.

This bending was not observed in other fields where lighter dosages were used.

Seed harvested from the various plots germinated normally, except from plots where the 2,4-D had come in direct contact with the grain itself. Only 74% of the seed from the plot treated July 24 germinated as compared to 90% from the control plots and the other treated plots. The germination in this instance was abnormal in that the primary root development was inhibited and there was an abnormal elongation of the mesocotyl region.

COMPARATIVE EFFECTIVENESS OF 2,4-D COMPOUNDS

Since a rather large number of 2,4-D compounds were available, a test was made with several in order to find out if some were more suitable than others in rice weed control. Paired plots of Zenith rice heavily infested with Mexican weed were sprayed April 29, 2 days before flooding, with four materials. The results, Table 2, showed that all materials used at a concentration of 1,000 p.p.m. and the methyl ester at 500 p.p.m. were effective in the control of Mexican weed. In this test the sodium salt, which killed 73% of the weeds, did not seem as effective as the acid plus sodium carbonate which killed 95% of the weeds. However, the water coverage in the plot sprayed with the sodium salt was poor, and this may have accounted for the difference. In another test where the two were compared there was essentially no difference in their effectiveness. The acid plus sodium carbonate is essentially a sodium salt. The differences in percentage of Mexican weeds killed by the Dow A 510, Weedone, and the methyl ester at 500 and 1,000 p.p.m. were probably not significant. The methyl ester at 250 p.p.m. was less effective, as only 33% of the Mexican weeds present in the plot were killed. The tests, however, did show that the control of Mexican weed materially improved the yield of rice, for increases of as much as 32 bushels per acre were secured in the treated plots.

TABLE 2.—*Comparison of the sodium salt with certain esters of 2,4-D on the control of Mexican weed, Caperonia castaneaefolia, in 1946.*

Material	Concentration, p.p.m.	Number weeds per sq. yd.			Yield in bu. per acre		
		Control	Treated	Per cent killed	Control	Treated	Difference
Sodium salt of 2,4-D	1,000	161	43	73	22.0	48.2	+26.2
Sodium carbonate + 2,4-D acid (Dow A 510)	1,000	128	7	95	21.6	53.6	+32.0
Weedone (ethyl ester 2,4-D)	1,000	127	14	89	43.2	58.7	+15.5
Methyl ester 2,4-D	1,000	243	8	97	23.8	50.0	+26.2
Methyl ester 2,4-D	500	134	15	89	32.4	51.5	+19.1
Methyl ester 2,4-D	250	134	90	33	32.4	40.7	+ 8.3

TEST WITH SINOX AND 2,4-D IN CONTROL OF MEXICAN WEED

Sinox and 2,4-D were tested under a number of different field conditions. The tests were made with plots in series of three. One of the outside plots was treated with Sinox and the other with 2,4-D. The center plot was left untreated to serve as a control. The tests were located on 10 farms at widely separated points in the rice area. Mexican weed was present in most tests and indigo and curly indigo in some of them.

The results from these tests are presented in Table 3. In five of these tests the herbicides were applied in sprays previous to flooding. In the other five tests the chemicals were applied 1 to 2 weeks after flooding, three as sprays and two as dusts. In the tests made before flooding, an average of 61% of the Mexican weeds were killed by Sinox and 71% by 2,4-D (Fig. 2). Significant increases in yield in the sprayed and dusted plots over the untreated plots were secured. The average increase for Sinox was 14.8 bushels and for 2,4-D 17.6 bushels per acre. In the five tests where the material was applied after flooding an average of 27% of the Mexican weeds were killed by Sinox as compared to 61% by 2,4-D. The average yield for the untreated plots was 22.0 bushels per acre as compared to 30.6 bushels for Sinox, and 40.3 bushels for 2,4-D. In the two tests where the dusts (Andrus 3 and 4) were used, there was much better control than where a spray (Andrus 2) was used. However, this would be expected since the dusts were applied at an approximate rate of 20 pounds per acre, about twice as much as was applied in the spray. In one of these tests (Andrus 4) there was a decrease in yield though Mexican weeds were controlled fairly well. This seemed to be due to the heavy growth of grass, principally *Brachiaria* Sp. The grass was

FIG. 2.—Effect of 2,4-D on Mexican weed in rice. Plot on left 8 days after spraying with 1,000 p.p.m. solution at rate of 100 gallons per acre. Plot on right untreated.

not injured by the herbicide and obtained a start when the growth of the rice was temporarily checked.

TABLE 3.—*The effect of Sinox and 2,4-D on the control of Mexican weed, Caperonia castaneaefolia, in 1946.*

Tests	Weeds per sq. yd.					Yield in bu. per acre		
	Control	Sinox		2,4-D		Control	Sinox	2,4-D
		Number	Per cent killed	Number	Per cent killed			
Treated Before Flooding								
Heinen.....	129	44	66	7	95	36.7	42.1	44.6
Robert 1...	75	15	80	50	34	5.4*	45.0	28.4
Andrus 1...	102	41	60	23	77	32.0	41.0	52.2
Lyons.....	16	13	19	0	100	42.1	47.2	47.2
Dugal......	146	62	56	53	63	37.1	51.5	60.1
Average....	93	35	61	27	71	30.6	45.4	48.2
Difference							+14.8	+17.6
Treated 1 to 2 Weeks After Flooding								
Robert 2...	63	57	10	14	88	14.0	23.8	48.2
Fontenot...	118	93	21	41	65	—	—	—
Andrus 2...	202	178	12	130	36	14.4	33.1	37.4
Andrus 3†..	201	102	49	51	75	23.4	38.2	47.2
Andrus†....	119	84	29	40	66	35.6	26.6	28.8
Average....	141	103	27	55	61	22.0	30.6	40.3
Difference							+8.6	+18.3

*Indigo present in the plots and was not removed until it had caused considerable damage.
†Herbicides applied as dusts.

The effectiveness of control with the chemicals was dependent upon treating Mexican weeds when they were small and following the treatment with good water coverage. In spots where water coverage was poor, new weeds emerged after treatment and a greater recovery of treated weeds was found than where water coverage was good. It was further noted that 2,4–D was more effective than Sinox on weeds that had passed the seedling stage. However, neither chemical was effective on Mexican weed when treatment was made more than 2 weeks after flooding.

TESTS WITH SINOX AND 2,4–D IN CONTROL OF INDIGO

Seven tests were made in fields where indigo was present. The results, Table 4, showed that 2,4–D gave consistently better control than Sinox. Three of the tests were made before flooding and four 1 to 2 weeks after flooding. While the results seem to indicate that the treatments made after flooding were more effective than before

flooding, this was due primarily to the poor control in the Robert 1 test in which only 64% of the indigo plants were killed by the Sinox and 68% by the 2,4-D. Water coverage was poor in this field and some weeds came up after treatment, obscuring the effects of the chemicals. Indigo is extremely sensitive to 2,4-D as shown by the fact that all plants were killed in five of the seven tests. This is also borne out by large-scale dusting tests made by farmers during 1946. In most cases, control of indigo was good. For good control, a higher percentage of the indigo than of the Mexican weeds must be killed because of the difference in the damage that the two weeds cause.

TABLE 4.—*The effect of Sinox and 2,4-D on the control of indigo, Sesbania macrocarpa, in 1946.*

Test	Control, No. weeds per sq. yd.	Sinox		2,4-D	
		No. weeds per sq. yd.	Per cent killed	No. weeds per sq. yd.	Per cent killed
Before Flooding					
Robert 1	22	8	64	7	68
Pierce	11	3	73	0	100
Lyons	49*	10*	90	2*	96
Average			76		88
1 to 2 Weeks After Flooding					
Robert 2	14	2	86	0	100
Fontenot	24	8	67	0	100
Andrus 2	24*	3*	87	0*	100
Andrus 3†	6*	0*	100	0*	100
Average			85		100

*Total number of indigo plants in plot.
†Sinox and 2,4-D applied as dusts.

TESTS WITH SINOX AND 2,4-D ON CONTROL OF CURLY INDIGO

Neither Sinox nor 2,4-D was effective when used on curly indigo as a spray, but were moderately effective when applied as a dust (Table 5). In two tests made prior to flooding, the dust application of 2,4-D killed 89% of the curly indigo plants, while only 11% were killed by the spray. In two tests made after flooding, the spray was ineffective, while dust applications in the same fields gave 89% control with Sinox and 96% with 2,4-D. The heavier dosage in the case of the dusts is probably the explanation for its greater efficiency, but the nature of the plant which makes it difficult to wet may be a factor also. Additional tests on curly indigo showed that a second application of 2,4-D made approximately 3 weeks after the first treatment, at about the time the curly indigo plants began to recover, gave satisfactory control of this weed.

TABLE 5.—*The effect of Sinox and 2,4-D on the control of curly indigo, Aeschynomene virginica, in 1946.*

Test	How applied	Weed count	Control No.	Sinox		2,4-D	
				Number	Per cent killed	Number	Per cent killed
			Before Flooding				
Pierce...	Spray	No. per sq. yd.	63	61	3	56	11
Benoit ..	Dust	No. per sq. yd.	9	—	—	1	89
			2 Weeks After Flooding				
Andrus 2	Spray	No. per plot	14	14	0	16	0
Andrus 3	Dust	No. per plot	27	3	89	1	96

SUMMARY

The effectiveness of Sinox and 2,4-D on three rice weeds, Mexican weed, indigo, and curly indigo, is reported. Their effect on rice is also described.

Sinox and 2,4-D were effective in controlling Mexican weeds when treated before flooding and when water coverage in the field after treatment was satisfactory. The 2,4-D was superior to Sinox when applied 1 to 2 weeks after flooding. Neither was effective when treatments were made 3 weeks or more after flooding.

Sinox was not as effective as 2,4-D in the control of indigo and curly indigo. Indigo was killed at any stage of development by 2,4-D, but curly indigo was somewhat more resistant to the chemical and for satisfactory control two applications made 3 weeks apart were often necessary.

Dusting was as effective as spraying for the control of Mexican weed and indigo and was more effective for the control of curly indigo.

Large increases in the yields of rice were obtained when weeds were controlled.

Corn Breeding: Gamete Selection, the Oenothera Method, and Related Miscellany[1]

FREDERICK D. RICHEY[2]

TWO technics in corn breeding recently have been outlined, namely, gamete selection (7)[3] and the Oenothera or multiple translocation method (1). It is proposed here to consider some miscellaneous facts and theories which bear on these technics, but which are, perhaps, as unrelated to each other as the "Cabbages and kings" of the Walrus in Lewis Carroll's phantasy.

GAMETIC AND ZYGOTIC FREQUENCIES

The two suggested technics present a common claim to value in that the frequency of "superior" gametes is much greater than that of zygotes that are homozygous for such "superior" gametes. Thus, it has been pointed out (1,7) that a frequency of one superior gamete per 100 gametes leads to a frequency of only 1 per 10,000 for zygotes that are homozygous for that superior gamete. Zygotes with two superior gametes are better, however, than individual gametes; such a homozygote therefore will be termed a "superlative" zygote, for convenience. But such superlative zygotes do not exhaust the superior gametes in the population; there are 198 zygotes in the 10,000, or nearly 2%, that will have one superior gamete. These heterozygotes constitute a satisfactory source from which ultimately to isolate superlative zygotes by selfing and selecting. Accordingly, they may conveniently be designated "satisfactory" zygotes. It seems worth while to explore the expected frequencies of these gametes and zygotes a little further.

Assume a population heterozygous at a single locus, $A\ a$. Let dominant A be enough better than its recessive so that its frequency will have been established at 60%, compared with 40% for that of recessive a. Gamete selection by either technic should then be successful in 60% of the cases, as it obtained dominant A. It would be a failure, and an irredeemable failure, in the 40% of the cases in which it did not obtain dominant A, that is, did obtain recessive a. Among the zygotes of such a population, on the other hand, 36% would be homozygous for dominant A and therefore superlative, and another 48% would be satisfactory, with $A\ a$ heterozygous. Accordingly, 84% of the zygotes would be satisfactory or better, and only 16% of zygotic selections would be expected to be total failures in obtaining dominant A. These proportions, and the corresponding ones for two and

[1]Joint contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the University of Tennessee Agricultural Experiment Station, Knoxville, Tenn. Also presented at a meeting of the Association of Southern Agricultural Workers in Biloxi, Miss., January 16, 1947, under the title "Corn Breeding: Gamete Selection, the Oenothera Method, Cabbages and Kings." Received for publication January 27, 1947.

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[3]Figures in parenthesis refer to "Literature Cited", p. 411.

for three loci are shown in Table 1. As the number of loci increases, the proportions of superior gametes and of superlative zygotes decrease, the latter much more rapidly. Although the frequency of satisfactory zygotes increases through the three loci, it, too, decreases when the number of loci gets larger. The population then rapidly becomes one in which completely superior gametes and completely satisfactory zygotes practically fail to exist.

TABLE 1.—*The decimal frequencies of the kinds of gametes and zygotes stated, and of expected total loss of favorable dominants at initial selection under gamete and zygote selection for from one to three loci, with the ratio of dominant to recessive as 0.6 to 0.4.*

Category	Number of loci concerned		
	1	2	3
Frequencies of:			
Superior gametes	0.60	0.36	0.216
Superlative zygotes	0.36	0.13	0.047
Satisfactory zygotes	0.48	0.52	0.546
Expected total losses under:			
Gamete selection	0.40	0.64	0.784
Zygote selection	0.16	0.35	0.407

The nonfixation of recessives by the selection of satisfactory heterozygotes at the initial choice may constitute an important advantage for zygote selection. This can be illustrated through a hypothetical example. Assume a plant heterozygous for 10 pairs of independent alleles, with the recessive of each determining an obvious defect. The chance of any random gamete carrying one particular dominant is ½, and that of its carrying all 10 dominants, i. e., no recessive defects, is only 1 in 1,024. If the plant were selfed, however, 1 of every 17.8 zygotes would carry none of the recessives in the homozygous condition. Selecting such defect-free plants and their similar progeny for breeding would rapidly eliminate the recessive genes from the population. This effectiveness of consistent selection is illustrated in Table 2. That table, however, is based on an assumed propagation of plants having either 0 or 1 expressed recessive, instead of only those having no expressed recessives as in the example above. This results in a mode for plants with one recessive instead of a mode for plants with no recessives.

In proposing his ingenious method for obtaining homozygotes by doubling gametes with the aid of translocations, Burnham (1) notes that other ways of doing this also have been suggested. The theoretical advantages claimed for such procedures have been the much greater frequency of superior gametes, and the saving in time otherwise needed to achieve homozygosis by inbreeding. To the writer it is a moot question whether the higher frequencies of superior gametes will compensate for the certain immediate fixation of deleterious recessives by any method for doubling gametes into homozygotes, as has already been discussed. There is some question, in fact, whether

homozygosis is not reached too rapidly to permit adequate selection even under self fertilization. Time can take the place of numbers, as nicely brought out by Macaulay (4) in his paper on plot inbreeding. If any method for obtaining homozygotes directly is successful, it should throw important light on the number and nature of the genes concerned, and on other vexed questions in corn breeding. Such a method also might be a practical approach to selecting from stocks previously purged of major recessive defects, even if it should prove unsatisfactory for selecting directly from varieties.

TABLE 2.—*Percentage phenotypic distribution in F_2 to F_7 from an F_1 heterozygous for 10 pairs of genes having a dominant-recessive relation, when only those individuals having 0 or 1 expressed recessives are propagated.*

Generation	Classes for the numbers of expressed recessives stated										
	0	1	2	3	4	5	6	7	8	9	10
F 2	5.6	18.8	28.2	25.0	14.6	5.8	1.6	0.3	a	a	a
F 3	3.7	22.4	33.5	25.0	11.3	3.3	0.7	0.1	a	a	a
F 4	5.0	38.7	36.0	15.6	4.0	0.7	0.1	a	a	a	a
F 5	6.4	56.8	29.0	6.8	0.9	0.1	a	a	a	a	a
F 6	7.6	70.9	19.0	2.3	0.2	a	a	a	a	a	a
F 7	8.3	80.0	11.0	0.7	a*	a	a	a	a	a	a

*Indicates less than 0.05%.

The rapid fixation of unfavorable recessives that would obtain by doubling maternal gametes in any way would not occur with "gamete selection" as outlined by Stadler (7). Any major recessive included in a gamete selected from the variety would have met its more favorable dominant in the initial cross with the "elite" inbred line. Effective selection then could eliminate the recessive in later generations. Moreover, any dominant favorable genes making the initial cross better than the elite line as a parent would have met their recessives in that initial cross. The value of the final line then would depend upon how successfully the recessives from both sources could be eliminated by selection in the subsequent generations.

EARLY TESTING

The possibilities for selection in the situation just described are essentially those which exist for selecting from a cross between two established lines. This is, of course, the way that Stadler (7) outlined it. It has been further emphasized by Hayes, *et al.* (2). The latter also raise the question whether it is necessary to begin with a cross shown by test to have combining power superior to that of the elite line itself. This question seems very pertinent. Suppose, for example, that the elite line to be improved had high combining power because it had dominant genes A, B, C, and that its recessives r and s added nothing. The cross with a selected gamete carrying A, B, C, R, s should be superior in combining power to the elite line because of its added dose of dominant R. Selection from this cross might isolate an inbred

that would have this dominant *R* in addition to the three dominants from the elite inbred. This would be the maximum that could be obtained from that particular cross. On the other hand, a cross of the elite line with a gamete *a*, *b*, *c*, *R*, *S* would have only five dominants in all, and be inferior in combining power to the elite line, but from it could be isolated a new inbred with all five dominants. This would be superior both to the elite line with three and to the other possible new line with four dominants. This failure to determine the best prospect is due to the fact that a tester cross cannot distinguish whether two dominants are at one or at two loci, as the writer has emphasized elsewhere (5).

A similar question can be raised as to the advantage of testing in the F_2 of the crosses as proposed by Stadler (7). The concept of early testing got much of its impetus from Jenkins' conclusion (3) in 1935 that the performance of inbreds in hybrids became more or less constant early in the breeding program. The writer (5) has shown, however, that Jenkins' data could at least as well be interpreted as opposed to early testing. He further showed (5) that genetic theory indicated no important advantage for early testing.

More recently, Sprague (6) has reported data on the yields of test crosses of S_0 plants and of their S_1 progeny. The frequencies in his Table 1 have been converted to percentages and are shown, with an interpolated average, in Table 3. The opportunity for obtaining high-yielding progeny from family 130 seems to be about as good as to do so from the three families whose S_0 crosses yielded from 10 to 18 bushels more than the parent of family 130. Sprague (6) notes that the correlation for parent and progeny yields of +0.85 is significant, even for the 4 degrees of freedom involved. However, the range of only 102.2 to 105.9 among four higher progeny yields leaves room for no correlation of importance within that group. As Sprague notes, most of the calculated correlation comes from the differences between the means of the higher four and the lower two families. To the writer, these data indicate the probable expenditure of considerable effort

TABLE 3.—*Acre yields of six S_0 tester-crossed plants in 1940, the mean acre yields of 20 tester-crossed S_1 progeny plants of each in 1942, and the percentage frequency distribution for the tester-crossed progeny.**

Family No. SSS	Acre yield		Percentage frequencies for acre yield (bushels) with the class centers stated (1942)					
	S_0 1940	S_1 1942	87.5	92.5	97.5	102.5	107.5	112.5
278	100.8	105.9	—	—	15	25	45	15
295	92.9	104.6	—	5	10	40	35	10
393	92.9	102.2	—	—	30	50	15	5
Average			—	2	18	38	32	10
130	82.5	103.3	—	—	30	25	40	5
227	73.5	94.1	20	40	25	15	—	—
407	64.9	97.3	5	25	45	25	—	—

*After Sprague (6).

for a very small gain from early testing. This opinion is supported by unpublished data at the Tennessee Station which indicate that the parents of very low-yielding test crosses are likely to be very low yielding as inbreds. There is thus a liklihood of their being eliminated in any event.

Knowing of the writer's interest in the question of early testing, Dr. A. M. Brunson sent him some unpublished data from an experiment under way and which bear on the problem. These record the yields of test crosses of 35 S_0 plants of a strain of Reid, in 1943, and the average yields of selected progeny plants in similar crosses in 1945. The latter are averages for 1 to 10 progeny in each of the 35 families, with a mean and mode of 4 progeny plants tested in each family. It is a sincere pleasure to thank Doctor Brunson for permission to use the data in the regression diagram shown as Fig. 1. This shows the regression of the progeny means in 1945 on the parental values in 1943. The regression for the whole 35 items is shown by the solid line, whereas those for the 30 higher and the 5 lower yielding parents are shown separately by the broken lines. The latter are both negative, the positive direction for the complete distribution resulting from the positive relation between the two group means. Of the 35 families tested, then, 5 very low combiners were adequately indicated as such. The writer would expect these to be so poor as inbreds that they would be eliminated quickly by simple selection. Among the 30 higher yielding families, the early test would have been actually misleading as to the potentiality of the parents. Again there seems little to recommend early testing as a basis for selecting inbreds.

SELECTED VARIETAL GAMETES FOR IMPROVING UNADAPTED INBREDS

In the light of the available evidence, the writer is unconvinced of any worth while advantage for the elaborate testing outlined as an integral part of Stadler's (7) method of gamete selection. On the other hand, the writer is in complete agreement with Stadler (7) as to the important need for sampling further the germ plasm of open-pollinated varieties, and that this can be done more efficiently by sampling for gametes than for zygotes. It also seems that this approach would have particular value for combining the virtues of good inbreds developed in one evironment with characters permitting their use in a different environment. Thus, the best inbreds developed in the Corn Belt are grossly unadapted to the South; they are too early maturing and susceptible to various insects and diseases. Excellently adapted varieties are available in the South, however, which have been very inadequately sampled as yet. It seems possible that more rapid progress could be made in obtaining satisfactory inbreds by using the best of the Corn Belt inbreds with which to select good gametes than by selecting directly for zygotes from these adapted varieties. It should be obvious that such a procedure can as well be regarded as one for the adaptive improvement of the inbreds. (It was in connection with adapting inbred WF9 to a longer growing season that Stadler (7) first outlined his gamete selection method.)

The writer prefers to think of it in this way so as to avoid confusion with Stadler's more elaborate method which seeks immediately to evaluate the combining power of the individual gametes.

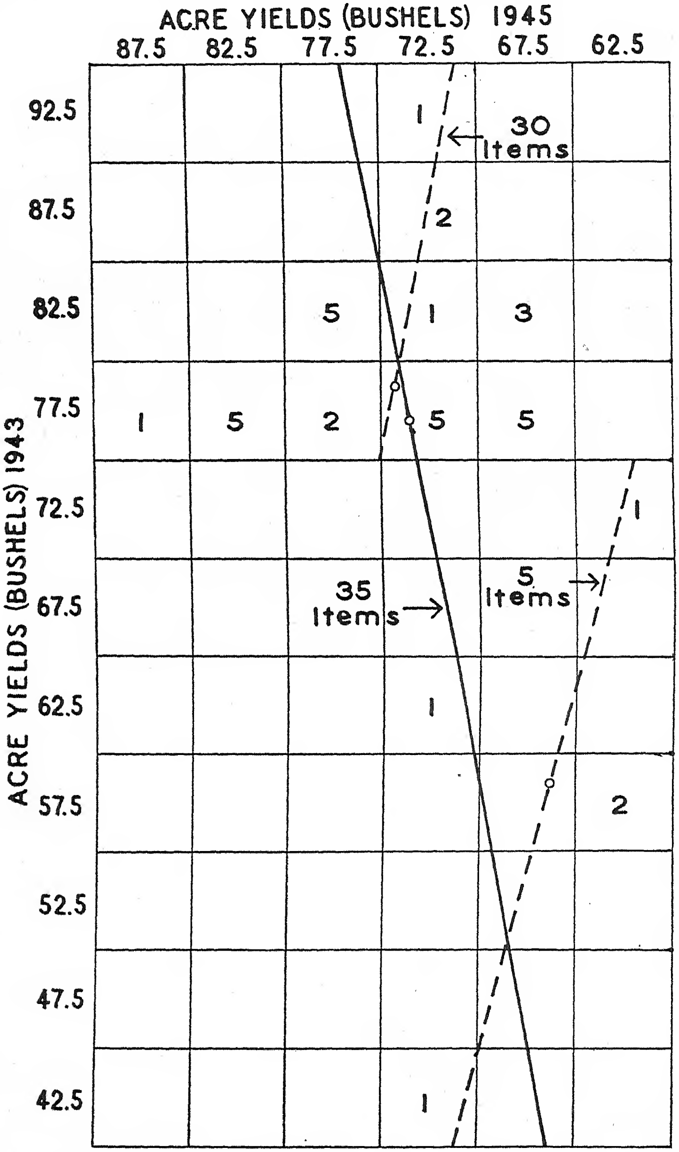

FIG. 1.—The regression of the yields of test crosses of progeny ears in 1945 on the yields of test crosses of the parent ears in 1943. The regression for the whole population of 35 parent ears is shown by the solid line; those for the 30 higher yielding parents and the 5 lower yielding parents are shown by the broken lines. (From data supplied by A. M. Brunson.)

A project involving this kind of gamete selection from the Huffman variety was initiated at the Tennessee Agricultural Experiment Station in 1943. Forty plants of the Huffman variety were selfed and outcrossed to four yellow inbreds from the Corn Belt, 10 plants to each. Selection in selfed lines was then practiced from these crosses and from the Huffman selfs. After three generations, reasonably good looking lines are available, in yellow and in white, from each of the four series of crosses. The crosses with Ohio 40B were inferior to the other crosses as a source of inbreds. There were marked differences among the crosses of individual Huffman plants to the same inbred. Linkage

TABLE 4.—*Number of days from planting to pollinating in sister rows from yellow and white seeds of the F_2 of crosses between individual plants of the Huffman variety (white) with earlier yellow inbred lines.*

Yellow parent	Huffman plant, No.	Pollinations		Mean days to pollination		
		White, No.	Yellow, No.	White, No.	Yellow, No.	y-Y, No.
Ohio 40 b	4	9	9	67.3	66.6	0.7
	4	4	4	66.0	66.5	−0.5
	4	9	6	71.1	68.3	2.2
	5	5	5	67.8	68.2	−0.4
	5	3	6	71.0	66.5	4.5
	8	2	1	68.0	63.0	5.0
	8	12	8	65.9	66.5	−0.6
Total or mean......		44	39			1.64
Moews M14	42	9	10	69.7	66.5	3.2
	42	8	10	68.8	65.7	3.1
	42	7	5	68.4	66.6	1.8
	17	5	5	66.0	64.4	1.6
	17	4	7	69.0	65.7	3.3
	22	2	5	69.5	65.2	4.3
	22	3	2	70.0	68.5	1.5
Total or mean......		38	44			2.69
RB 751	25	9	7	70.8	71.1	−0.3
	25	5	9	72.6	70.3	2.3
	29	6	9	69.8	70.1	−0.3
	29	4	8	72.5	72.5	0.0
	31	4	2	68.8	69.0	−0.2
	31	1	1	74.0	73.0	1.0
	31	4	4	73.3	69.5	3.8
Total or mean.....		33	40			0.9
RB 893	36	6	2	73.0	69.0	4.0
	38	2	5	69.5	70.2	−0.7
	38	1	3	67.0	67.7	−0.7
	38	3	5	68.0	68.4	−0.4
	38	1	2	66.0	66.0	0.0
Total or mean.....		13	17			0.44
Grand mean						1.65

has been a minor hindrance. Linkage of endosperm color with number of days to silking, and with dieing-between-the-veins is indicated by the data in Tables 4 and 5. In other yellow-white crosses there was at least a suggestion of linkage between a gene for resistance to early ear-worm damage and endosperm color (Table 6). Moreover, there has been a definite tendency for the yellow selections to incline more toward the ear and plant type of the yellow parents, and, on the other hand, it has been somewhat easier to get later isolates and better husk protection from the white selections. Linkages have not been strong enough, however, to interfere seriously with the program.

TABLE 5.—*Association of dieing-between-the-veins with the endosperm color of the seed planted in the F_2 of the cross yellow-resistant×white susceptible.*

Kind of seed planted	Number of plants		
	Total	Normal	Affected
Yellow	31	31	0
White	25	16	9
White parent, selfed	13	8	5

TABLE 6.—*Association between ear-worm damage to young plants and the endosperm color of the seed planted in the F_2 of the cross yellow-resistant×white-susceptible.*

Yellow seeds planted						White seeds planted			
Row	Total No. of plants	Plants damaged				Row	Total plants, No.	Plants damaged, all heavily	
		Heavily, No.	Lightly, No.	Total				No.	%
				No.	%				
24	17	8	0	8	47	25	19	12	63
27	20	2	5	7	5	28	18	9	50
29	20	0	4	4	30	30	19	9	47
All	57	10	9	19	32	All	56	30	54

Nothing will be known as to the combining value of these new lines until the test crosses made of them have been tried in 1947. It may be stated definitely, however, that a higher proportion of more satisfactory appearing inbreds has been derived from the crosses than from the selfs of the Huffman parent plants that have been handled much the same way in the nursery. Pending the results of the yield trials, excessive enthusiasm should be avoided. So far, however, the method followed seems to have had the advantages which theory would lead one to expect for it.

SUMMARY AND CONCLUSION

New approaches to the isolation of better inbreds for producing better corn hybrids continue to be suggested. Some of these have been discussed briefly in the preceding paragraphs. The writer has agreed with some of the postulates and conclusions and has questioned the validity of others. In concluding, he wishes only to emphasize that whether or not a new method is 100% right is not important. The important thing is the suggestion of new methods, their discussion pro and con, and additional experiments to prove their possibilities and limitations. That can only result in a continued progress for corn breeding in the future as in the past.

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Effect of Method of Grazing Unimproved Kentucky Bluegrass on Beef Production, Botanical Composition, and Herbage Yields[1]

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DESPITE proved methods of pasture improvement through the use of lime, fertilizer, and the introduction of legumes, the major part of the pasture acreage of the corn belt still consists of unimproved Kentucky bluegrass. These pastures vary tremendously in productivity, with many of them heavily infested with ragweeds, povertygrass, and other undesirable species, which compete with bluegrass for moisture, light, nitrogen, and other nutrients.

There is good evidence that in many cases the differences observed may be attributed to the method of grazing. Aldous (2)[3] found that deferring grazing of bluestem pastures until about June 15 gave an increase of approximately 25% in carrying capacity and a 33% in livestock gains over pastures grazed season long. The closeness of clipping Kentucky bluegrass in one year was found to influence yields the following year in studies by Graber (6). Daubenmire (5) and Sarvis (9) found that certain unpalatable species increased under heavy grazing, while Hein and Cook (7) reported that Kentucky bluegrass and white clover predominated over taller species, such as timothy and orchard grass, following 6 years of continuous heavy grazing of a complex pasture mixture. Ahlgren (1) found moisture and fertilization more important than cutting treatments in determining productivity of bluegrass.

The object of the study here reported, undertaken in 1939, was to determine the effect of grazing management of unimproved Kentucky bluegrass on beef production, botanical composition, and forage yields. The results indicate some of the reasons for the deterioration of pastures and provide information of value in developing better grazing management systems.

METHODS

Six pastures, ranging in size from 4.45 to 5.20 acres of typical permanent pasture on the College Pasture Improvement Farm near Albia, in Monroe County, Iowa, were used in this study. The predominant soil types are Clinton silt loam and Lindley silt loam, much of the latter sloping more than 13%, and with only 2 to 4 inches of top soil remaining.

The area had never been plowed, limed, or fertilized. At the beginning of the experiment Kentucky bluegrass, *Poa pratensis* L., was the predominant species with some redtop, *Agrostis alba* L., a trace in spots of white clover, *Trifolium repens* L., and a very few weeds.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 421.

Two systems of grazing management were compared in triplicate. The one, moderate continuous grazing, involved grazing from about mid-May to mid-October at a constant carrying capacity throughout the season although seasonal variations in production made it impossible to adhere strictly to this rule. The consumption of grass was considerably below the carrying capacity early in the season in order to provide ample forage during midsummer when growth was greatly retarded.

The other system of management called for heavy grazing in the spring and fall, when the growth of grass was most rapid, then removal of cattle during midsummer until fall rains and cooler weather revived growth. The time of turning on in the spring and removal in the fall was the same for both systems of grazing management. The two systems of management were followed from 1940 through 1944. In 1945 the treatments were reversed on the pastures to even the conditions of the pastures in preparation for new experiments. Gains by cattle for 1945 are not reported here.

Native yearling steers, wintered on the farm, were used. Each steer was tagged and weighed individually on three consecutive days at the beginning and at the end of the grazing seasons and once at monthly intervals during the grazing period.

Attempts were made during 1944 and 1945 to determine the effect of previous grazing treatments upon yields of herbage in the pastures, by periodically clipping and weighing the grass harvested from 72 cages, each 4×4 feet, with 12 cages located in each pasture. Because of the large number of variables which influence the yield under small cages in pasture an attempt was made to measure some of the variables and thus remove them as a source of experimental error in measuring treatment differences.

The effect of soil differences on production was measured in 1944 and 1945 by locating six cages on each of the two major soil types in each pasture. This was done by selecting two areas, each 60×60 feet, considered typical of the two soil types. These selected areas were divided into three strata, each 20 feet wide. Two cages were located in each stratum.

The effect of previous closeness of grazing on subsequent yield was measured by locating one of the cages in each stratum on an area which animals had closely grazed in previous seasons and the other on an area not closely grazed. The exact location of the cages was at random, after mapping the closely grazed and ungrazed areas. The accumulated dead growth was clipped and removed early in the spring of 1944 when the cages were placed.

Two clippings were made in 1944 and three in 1945. The harvested herbage was dried for 3 days at about 110° F and yields recorded in tons per acre at 12% moisture. Because of the limitations of the sampling procedure, no attempt has been made to relate directly forage yields and gains made by cattle.

Botanical composition readings were made by estimating the proportion of different grasses and weeds present in the vegetative cover. Readings were made of the herbage under the cages just before the fall clipping in 1944 and before each of the three clippings in 1945. These were recorded as estimates of percentages of the total herbage under the cage.

EXPERIMENTAL RESULTS

CATTLE GAINS

Cattle were turned on all pastures on the same dates in the spring and, with one exception, were removed from all pastures on the same dates in the fall. Pastures grazed heavily in spring and fall usually were not grazed during late July, August, and early September, when bluegrass was largely dormant (Table 1).

The average annual gain made by cattle on pastures grazed heavily spring and fall was 19 pounds greater, or 15%, than those from pastures grazed continuously at a moderate intensity. This was significant beyond the 5% level (10). This system gave larger gains in each year, except 1941 when gains from the two management systems were

TABLE 1.—*Length of grazing seasons and deferment periods of six experimental pastures, three of which were grazed continuously and three grazed heavily spring and fall only.*

Year	Date turned on pastures	Date removed from pastures	Period off pastures grazed spring and fall only
1940	May 18	Nov. 3*	July 9 to Sept. 25
1941	May 11	Oct. 17†	July 9 to Sept. 16
1942	May 16	Oct. 9	July 10 to Sept. 5
1943	May 12	Oct. 9	June 30 to August 26
1944	May 12	Oct. 11	July 4 to Sept. 7
1945	May 17	Oct. 14	July 21 to Sept. 28

*Removed from pastures 1 and 4 on October 23.
†Cattle off continuously grazed pastures from August 28 to September 16.

identical. As shown in Table 2, the gains varied greatly in different years, with 1940 gains twice those for 1942. These differences were highly significant and may be attributed largely to weather conditions although the extremely low 1942 production was caused in part by the use of nervous cattle which never became accustomed to handling.

The daily gains of cattle under moderate continuous grazing averaged 1.16 pounds during the 5-year period and ranged from a low of 0.90 pound in 1942 to a high of 1.35 pounds in 1944. The system of heavy grazing in spring and fall gave average daily gains of 1.26 pounds. Daily gains for different years ranged from 0.78 pound in 1942 to 1.77 pounds in 1944. The greater production in acre gains under the spring and fall system of grazing was partially due to larger daily gains and partially to increased pasture days per acre.

TABLE 2.—*Yields per acre in terms of pounds of animal gain from six experimental pastures grazed by two management systems from 1940 through 1944.*

Replication	Grazing season					
	1940	1941	1942	1943	1944	Ave.
	Moderate Continuous Grazing					
1	157	129	82	125	135	129
2	152	134	73	110	160	126
3	162	140	83	92	123	120
Av.	163	134	79	109	139	125
	Heavy Grazing Spring and Fall					
1	207	101	82	160	138	138
2	175	146	44	125	164	131
3	180	156	137	156	188	163
Av.	187	134	88	147	163	144
	Average Both Treatments					
	175	134	84	128	151	134.5

Differences in animal gains per acre cannot be attributed solely to the effect of management on the yield of grass. The palatability of the herbage at the time it was consumed varied somewhat under the two systems. Also, as shown by Brown (4), the protein content of Kentucky bluegrass declines and crude fiber and lignin increase as the grass reaches maturity. Under continuous grazing a considerable part of the spring growth matures before it is consumed. Under the other system of management most of the grass is consumed in the immature stage of growth.

High temperatures, flies, reduced palatability, and differences in chemical composition, all are factors which are believed to have reduced gains made by cattle on pastures grazed continuously, for midsummer gains are not considered in the other lots. Gains made and acreages required by the steers while off the pastures grazed heavily spring and fall are not included as part of this study.

There was an accumulation of ungrazed grass during late May and June under the system of continuous grazing. A noticeable characteristic of this management system was the presence of closely grazed and ungrazed areas. Even at the end of the grazing period the spotting was marked, with spots on which there had been little grazing interspersed with areas which had been grazed very closely. It was observed that the same spots were left ungrazed from year to year. The presence of manure or urine deposits may have some influence at the start on which areas were left ungrazed. Differences in palatability due to age of growth influenced grazing habits as the season progressed.

The spotted grazing characteristic was much less noticeable on pastures grazed heavily spring and fall, although even here some areas were more closely grazed than others, though by the time the animals were removed in early July most of the grass had been consumed

BOTANICAL COMPOSITION

The most significant result of the two systems of grazing management was the differences which developed in the vegetative composition of the pastures. Estimates were made of the percentages of the principle species present in the vegetative cover under 72 cages located on different soils and on grazed and ungrazed areas in each pasture. Readings were made just previous to harvesting the herbage for yield determinations.

Two annual weedy grasses, crabgrass, *Digitaria sanguinalis* (L.) Scop., and poverty grass, *Aristida oligantha* Michx., had increased considerably in the second year on pastures grazed only in the spring and fall. These and other weedy species increased in abundance as the experiment continued. No important changes were observed in the botanical composition of pastures under moderate continuous grazing during this same period.

Readings made in October 1944 and 1945 showed nearly 30% more weedy grasses on the pastures which were not grazed in midsummer than on pastures grazed continuously at a moderate intensity. These October readings, as shown in Table 3, were of the accumulated

TABLE 3.—*Estimates of the percentage of weeds and weedy grasses present in the herbage under 72 cages located on two soil types in six pastures grazed by two methods.*

Treatment	Moderate continuous grazing, %	Heavily grazed spring and fall, %	Difference, %
October 13, 1944....	15.1	45.3	30.2
October 11, 1945....	30.4	60.0	29.6
Closely grazed spots*	28.0	60.8	32.8
Ungrazed spots......	17.5	44.5	27.0
Clinton soil.........	21.6	47.1	25.5
Lindley soil.........	23.9	58.3	34.4

*"Closely grazed" and "ungrazed" spots refer to the condition of the grass previous to the time that the cages were located in the pastures in the spring of 1944. There was no grazing under cages during 1944 or 1945 and clipping treatments were identical on all caged areas through this period.

growth under cages following clippings on June 16 and July 25, respectively, for the two years.

There were nearly 15% more weedy species present under both management systems in 1945 than in 1944. This increase was attributed to a prolonged dry period during the summer of 1944 which retarded the growth of the annual grasses. Areas which had been closely grazed under both management systems showed a higher percentage of weeds than spots which had been ungrazed.

Differences in the fertility of the soil were reflected in the percentage of weeds present, particularly under the system of heavy spring and fall grazing. The more fertile Clinton soils, found on the more nearly level ridge tops, were less weedy than the thinner Lindley soils, characteristic of the slopes.

Estimates of vegetative cover by species were made June 8, July 19, and October 11 in 1945. The grass was clipped and removed immediately following these dates so the estimates represent the growth during the intervals. As shown in Table 4, Kentucky bluegrass comprised 74% of the vegetative cover in June on pastures grazed continuously. July readings dropped to 47%, while an increase to 64% was obtained in October. A considerable part of the vegetative cover

TABLE 4.—*Average estimated percentage of different species present in the vegetative cover at various dates in 1945 on pastures grazed by two methods.*

Date	Blue-grass	Red top	Other grasses	Sedges	White clover	Crab-grass	Poverty-grass	Mics. weeds
			Moderate Continuous Grazing					
June 8	74	5	5	4	2	0	0	10
July 19	47	6	12	11	4	1	0	18
Oct. 11	64	6	8	2	0	10	3	7
			Heavily Grazed Spring and Fall					
June 8	61	10	5	9	2	0	0	13
July 19	27	10	11	18	5	7	0	21
Oct. 11	35	5	7	1	0	29	19	3

in July was composed of unpalatable sedges, miscellaneous weeds, and a variety of miscellaneous grasses. Crabgrass composed 10% of the October vegetation.

The heavy grazing in spring and fall had favored the growth of sedges and miscellaneous weeds in the June and July readings with corresponding decreases in Kentucky bluegrass. In October, Kentucky bluegrass comprised only 35% of the vegetative cover, with crabgrass ranking second with 29% followed by povertygrass with 19%. These seasonal changes in botanical composition had considerable influence on the yields of herbage obtained from the caged areas.

EFFECT OF GRAZING MANAGEMENT UPON SUBSEQUENT YIELDS

An effort was made in 1944 to determine the influence of the grazing management systems used from 1940 through 1943 upon the subsequent yields of grass when uniformly harvested. Yields were obtained from clippings made June 16 and October 13 under 72 cages. It was decided, after obtaining the 1944 yields, that clippings should be made in the same locations another year to determine whether the observed differences would tend to become equalized by uniform treatment. The 1945 clippings were made June 12, July 25, and October 12.

It was obvious from the start of this experiment that herbage yields alone would not properly represent the grass consumed by cattle. The crabgrass, which had come into the pastures not grazed in midsummer, contributed very little forage before the cattle were removed in July. Growth was rapid and unmolested during late July, August, and until cattle were returned for grazing in September. The lush growth of crabgrass was eaten readily for a few weeks before it matured, or was killed by frost.

Povertygrass, also present on pastures ungrazed in midsummer, was not observed to have been grazed at all. This species, like crabgrass, does not come on until late spring and grows most rapidly during the heat of midsummer.

The primary purpose of the clipping studies was to measure differences attributable to management systems. There were, however, numerous other factors which influenced yield. Most important of these were the closeness of grazing and the soil type. The experiment was designed, therefore, to measure variations attributable to these factors. A split-plot design was used with management systems as whole plots, subdivided under two soil types, which in turn were subdivided into ungrazed and closely grazed plots.

The June yields were approximately the same for the two management systems in both years, as shown in Table 5. The October yields in 1944 of the caged areas which previously had been grazed heavily spring and fall were nearly double those of continuous grazed pastures, indicating the influence in the autumn of the crabgrass and poverty grass. The total seasonal difference in yields of 0.40 ton in 1944 was highly significant (Table 6). The difference in treatments in 1945 was only 0.17 ton, which was not statistically significant but tended to show differences in previous grazing treatment even in the second year of uniform treatment.

TABLE 5.—*Summary of herbage yields in tons of hay per acre at 12% moisture for various clippings and treatments in 1944 and 1945.*

Clipping or treatment	Previous grazing treatment				Average both systems	
	Moderate continuous		Heavy spring and fall			
	1944	1945	1944	1945	1944	1945
June	0.56	0.69	0.56	0.67	0.56	0.68
July	—	0.34	—	0.37	—	0.36
October	0.48	0.48	0.88	0.64	0.68	0.56
Total	1.04	1.51	1.44	1.68	1.24	1.60
Clinton soil	1.15	1.71	1.62	1.96	1.38	1.84
Lindley soil	0.92	1.33	1.26	1.41	1.09	1.37
Closely grazed areas	0.69	1.16	1.39	1.51	1.04	1.34
Ungrazed areas	1.38	1.88	1.49	1.86	1.44	1.87

The relative proportion of weeds on the pastures managed by the two methods was almost identical in the two years. Thus, it appears

TABLE 6.—*Analysis of variance of the 1944 and 1945 yield data from 72 caged areas located on closely grazed and ungrazed places on two soil types on pastures previously grazed by two methods.*

Source of variation	Degrees of freedom	Mean square	
		1944	1945
Replications	2	212	7,929
Management systems	1	41,772**	4,640
Replications × managements (error a)	2	153	1,458
Soils	1	21,590	37,265*
Soils × management	1	1,027	1,407
Error b	4	3,962	4,185
Grazings†	1	39,331**	48,361**
Grazings × managements	1	22,969*	5,904
Grazings × soils	1	768	881
Error c	9	2,594	3,272
Clippings	1‡	15,914**	55,623**
Clippings × managements	1‡	41,419**	4,516*
Clippings × soils	1‡	209	966
Clippings × grazings	1‡	22,188**	9,197**
Error d	20‡	3,070	1,327
Total	47§		

*F value exceeds 5% level of significance.
**F value exceeds 1% level of significance.
†Ungrazed and closely grazed areas.
‡The 1945 yields have double these degrees of freedom.
§The 1945 yields have 71 total degrees of freedom.

that part of these yield differences in 1945 may be attributed to differences in the physiological growth response of the grass to the management systems and that these differences had been nearly eliminated in the second season by the uniform clipping.

The Clinton soils of the more level ridge tops yielded more in both years and for both grazing management treatments than did the Lindley soils of glacial origin found characteristically on the slopes. However, only the 1945 yield difference of 0.47 ton between the Clinton and Lindley soils was statistically significant beyond the 5% point. The yields in 1944 were lower than those of 1945 due to a prolonged drought period in midsummer. This factor undoubtedly restricted the full expression of soil differences. There is little doubt but that the yields of forage on both soils could have been very materially increased by nitrogen fertilization or by the introduction of legumes.

Highly significant differences were obtained in both years between the areas previously close grazed and those largely ungrazed. The most striking differences were obtained in June, 1944, from pastures which had been grazed continuouly, with the ungrazed areas yielding just double the 0.69 ton per acre obtained on areas which previously had been close grazed.

Spotted grazing was most pronounced on the pastures grazed at the lighter intensity early in the season. On pastures grazed heavily spring and fall, this tendency was less pronounced. This accounts for the significant interaction of grazings (closely grazed and ungrazed areas) ×management treatments obtained in 1944. In the analyses shown in Table 6, none of the second order interactions nor the one third order interaction was significant and therefore all were combined with their respective error terms.

Biswell and Weaver (3) showed that frequent clipping of prairie grasses decreased ground cover and root growth, prevented rhizome development, and resulted in the death of many old rhizomes. Hughes (8) found that close cutting of Kentucky bluegrass gave higher yields of grass but that early season growth was noticeably weaker, the plots became increasingly weedy, and there was a marked reduction in weight of roots and rhizomes. The heavy spring and fall grazing reported here is comparable to the close clipping studies in that the leaf area was kept at a minimum. The heavy infestation of the weedy grasses under this treatment was the most serious effect of the management system, the weedy annual grasses crowding and shading the perennial bluegrass more and more. It can be said, however, that the bluegrass sods weakened by overgrazing appeared to recover rather quickly when protected from grazing.

The highly significant differences between yields for the different clippings for both years are of no particular practical significance. The significant interactions of clippings×management systems in both years may be explained by the very heavy growth of weeds in the October clippings from pastures which had been grazed heavily spring and fall. A similar explanation may be made for the highly significant interactions in both years of clippings×closeness of grazing. It is noteworthy that these differences were still highly

significant two years after the cages were placed, thus preventing further differences in grazing.

The cage system for measuring yields of herbage in pastures has been justifiably criticised for its inadequacy in sampling, particularly with variable soils and stands of grass. The labor and expense involved in periodically harvesting 72 cages located 12 per pasture were considerable so that the addition of more cages to each pasture seemed impractical. The size of the experimental error could be reduced by sampling from a less variable population and by measuring and classifying those variables not directly related to differences in the systems of management. This was done by selecting in each pasture an area on each of the two major soil types which was considered representative of these soils in the pasture as a whole. Within these selected areas were differences in turf brought about by spotted grazing. The ungrazed and grazed areas were mapped and cages located on each at random.

By using this method of sampling, it was possible not only to measure much smaller differences in the management systems but also to obtain additional data on soils, effect of spotted grazing on yields, and the interaction of many of these factors. The interpretation of data thus obtained must be restricted to the areas sampled and not to the pastures as a whole. In this experiment it was considered not advisable to attempt to relate directly forage yields with gains made by cattle in the pasture.

The following conclusions on proper management of bluegrass pastures, based upon the data here reported, together with published work of other investigators and the writers' judgement and observations, would appear to be justified:

1. Continuous grazing is preferred to early and late season grazing only as the absence of summer grazing favors the development of annual weedy species which might otherwise be eaten when in the more succulent stages of their growth. This conclusion has been drawn in conscious recognition of the fact that larger cattle gains and herbage yields were obtained from early and late season grazing. The sacrifice in gains appears justifiable for maintaining a satisfactory perennial grass sod.

2. Grazing at full carrying capacity in the spring weakens the sod, decreases ground cover, and favors establishment of weedy annual species.

3. Grazing at less than full carrying capacity in the spring encourages spotted grazing, but it is recognized that this result may be lessened by turning on grass considerably earlier than the approximate May 15 date used in these experiments.

4. A good grass cover should be present on the pastures as the midsummer period of heat and drought approaches, as this provides insulation from the sun and discourages the establishment of weeds.

5. Clipping of pastures in early July is a valuable aid in controlling weeds and promoting uniform grazing.

6. Careful management, even at its best, is not a substitute for

pasture renovation involving some form of tillage, soil treatments, and the establishment of adapted legumes.

SUMMARY

1. Two systems of grazing management were compared on 28.92 acres of typical unimproved bluegrass pasture land in Monroe County, Iowa, from 1940 through 1945.

2. Gains made by yearling steers averaged 125 pounds per acre by continuous grazing at a moderate intensity and 144 pounds per acre when pastures were grazed heavily in spring and early summer and in late summer and fall, with no grazing during approximately two months in midsummer. The difference was statistically significant.

3. Pastures grazed heavily in the early and late parts of the season only contained progressively more annual weedy grasses as the experiment continued, October estimates in 1944 and 1945 showing approximately 30% more weeds in these pastures than in continuously grazed pastures. The principal weedy species were crabgrass, *Digitaria sanguinalis* (L.) Scop., and poverty grass, *Aristida oligantha* Michx.

4. Herbage yields from cages used to determine the residual influence of the grazing management systems in previous years showed highly significant differences in yields in favor of early and late season grazing in 1944, but a difference of only 11% in 1945 was not statistically significant.

5. Spotted grazing influenced herbage yields in subsequent years, with the previously "ungrazed spots" producing significantly more in both 1944 and 1945 than areas which previously had been closely grazed.

6. Herbage produced on Clinton silt loam yielded 27 and 34% more in 1944 and 1945, respectively, than on Lindley silt loam, although only the 1945 yields differed significantly.

7. Methods of managing unimproved bluegrass pastures are discussed.

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Segregation of Resistance to Bacterial Wilt in Crosses Involving Grimm Alfalfa[1]

Fred Reuel Jones and William K. Smith[2]

AFTER resistance to common leafspot and to downy mildew of alfalfa was recognized in 1942, selected plants resistant and susceptible to both of these diseases were selfed and crossed. Since the crosses involved wilt-susceptible and resistant or immune plants, tests of resistance to wilt were made in all parents and progeny. The F_1 generation in such crosses was found to contain plants differing widely in resistance, and the behavior of the F_2 generation appeared to be correlated with the behavior of the plants selected in the F_1 generation. This finding appears to help explain previously reported results of such crosses, and also to facilitate procedure in the introduction of the resistant character into susceptible stock.

Brink, Jones, and Albrecht[3] reported that crosses between plants of the highly susceptible Grimm variety and highly resistant plants gave few or no resistant plants in the F_2 generation, while crosses between the same resistant plants and plants of Hairy Peruvian or of *Medicago falcata* which seemed equally susceptible with Grimm gave in some instances high percentages of wilt-resistant plants in the F_2 generation. The conclusion was drawn here that "Grimm alfalfa appears to be of a genetic composition, with respect to the factors conditioning resistance and susceptibility, which permits relatively few wilt-resistant segregates with highly resistant Turkistan." However, 2 years later after having tested many more crosses, Albrecht[4] in an unpublished thesis, refers to this conclusion and states on the basis of additional data that hybrids between resistant Turkistan and Grimm do not differ significantly in reaction from those between Turkistan and Hairy Peruvian. The published abstract of this work[5] concludes that "The data indicate that resistance may be introduced by means of hybridization into any of the more commonly grown susceptible varieties of alfalfa." In the thesis study the only group of F_1 plants tested for resistance was from crosses between susceptible plants and those of intermediate resistance. In this group only two plants escaped with slight infection.

Since the work cited above was done, much work has been expended in an effort to provide a classification of resistant plants that might

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[1]Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis., in cooperation. Received for publication January 30, 1947.

[2]Senior Pathologist, U. S. Dept. of Agriculture, and Associate Professor of Agronomy and Genetics, Wisconsin Agricultural Experiment Station, respectively.

[3]Brink, R. A., Jones, F. R., and Albrecht, H. R. Genetics of resistance to bacterial wilt in alfalfa. Jour. Agr. Res., 49:635–642. 1934.

[4]Albrecht, Herbert Richard. The inheritance of resistance to bacterial wilt in alfalfa. Doctorial Thesis, University of Wisconsin Library. 1938.

[5]———. The inheritance of resistance to bacterial wilt in alfalfa. Summaries of Doctorial Dissertations, University of Wisconsin, 3:32–33. 1938.

be of more service in the genetic analysis of the results of crosses. A refinement of the present classification, based chiefly on the rate at which infected plants succumb, appears useless. Thus, for present convenience, three classes are used. Immunity appears to exist in a small percentage of plants in highly resistant varieties. Immunity can be determined with considerable certainty by inoculation in two successive years, or in a shorter period of time by the inoculation of four or more well-grown cuttings in one year. At the other end of the scale plants of Grimm alfalfa are comparatively uniform in susceptibility, though exceptions have been found. In three instances apparently immune plants have been obtained by selfing in successive generations of plants in which wilt progressed much more slowly than in most plants; and thus doubt of the complete susceptibility of this variety is aroused. Between these extremes are found such plants as comprise a large part of our present resistant varieties—plants in which the rate of disease development differs greatly. Thus, when the resistance of a plant is stated, it may be given quite precisely as immune, or less precisely like Grimm, or still less precisely as approaching Grimm. Thus, these classes are still to some degree based on the opinion of the classifier and are not yet adapted to serve genetic analysis.

The first cross in which the great variation in resistance in the F_1 generation was noted was between immune A116–15 and Grimm No. 8, one of the rare plants capable of infection in clones through dipping the cutting when made in bacterial suspension. This behavior is taken to represent the highest susceptibility in Grimm. From the cross made on G 8 as the pistillate parent several F_1 plants were selfed along with the parents. From each of the 50 seedlings from the pistillate parent, 70 seedlings from the staminate parent, and 170 seedlings of the F_1 plant producing most seed four or five cuttings were made, and the clones thus produced were inoculated and set in the field in the spring. Seedlings from two other F_1 plants were inoculated directly. Forty per cent of the clones from the progeny of the resistant parent were not infected, while none of the clones from the susceptible parent or the F_2 plants selected for cloning escaped infection, through in the latter group infection in a few clones was slight. However, the two F_2 populations which were inoculated directly gave 35 and 62% of uninfected plants. Two additional F_2 populations from a similar cross gave 17 and 44% of resistant plants. Reinoculation of some of these uninfected plants the following year gave ample evidence that this record of high resistance was not due to failure of infection the first year.

Meantime attention was turned to resistance in the F_1 generation. The F_1 plant from which the 170 F_2 plants had been obtained was found dead in the nursery under conditions indicating wilt as the probable cause of death, though this was not determined with certainty. The four F_1 plants from which partly resistant populations had been obtained appear to be immune. Other crosses had been made between immune plants and the two Grimm plants with the usual degree of susceptibility, and samples of the F_1 generation were tested for wilt with the result shown in Table 1. One or more apparently immune plants were found in each population, and the other plants

appeared to range in susceptibility from near immunity to the behavior of Grimm. A complete examination of the range and of the distribution of the plants within this range was not possible with the small number of F_1 plants available. A more extensive series of crosses have been made to serve these purposes.

TABLE 1.—*Plants found wilt immune in the first generation of crosses between susceptible Grimm alfalfa plants and wilt immune plants.*

Crosses	F_1 plants tested	F_1 plants immune
Grimm 3×T38-11	10	1
T28-5×Grimm 8	11	2
Grimm 8×A116-15	7	2
T37-1×Grimm 27	6	1
Grimm 27×A116-15-1	10	1
A116-15-1×Grimm 27	14	2

The results given here appear to be in agreement with Albrecht's unpublished results cited above, and to support his conclusion that resistance may be introduced into the commonly grown susceptible varieties. In addition, it appears that selection in the F_1 generation may lessen the labor involved. A similar diversity of behavior of leaf-spot resistance in the F_1 generation of crosses between resistant and susceptible plants is indicated in preliminary field experience with such crosses, and thus it is suggested that this behavior may be anticipated in the inheritance of still other characters in this plant.

Yield and Viability of Kentucky Bluegrass Seed Produced on Sod Areas Treated With 2,4-D[1]

PAUL C. MARTH, VIVIAN K. TOOLE, AND EBEN H. TOOLE[2]

IT has been estimated that as much as 40% of the Kentucky bluegrass seed harvested from weedy fields may be lost in cleaning and removal of weed seeds. The use of a selective herbicide, such as 2,4–D (2,4–dichlorophenoxyacetic acid) to eliminate weeds before harvest would therefore be of considerable value, providing seed quality is not diminished. Experimentally, 2,4–D as the dry acid or one of its salts effectively killed certain weeds from sod areas when applied in dry mixture with a carrier such as sand or complete fertilizer (5, 6).[3] This method of application appears to have definite merit in treating large areas since heavy, costly spray equipment is not required. Experimentally, the ordinary grain drill with fertilizer attachment has been satisfactory for applying such mixtures.

Since 2,4–D is a very potent growth regulator, it is important to determine the possible effects of this chemical on seed production in Kentucky bluegrass and other grasses. This paper presents data obtained on the yield and viability of blue grass seed harvested from plots that had received varying amounts of 2,4–dichlorophenoxyacetic acid applied in dry mixture with complete fertilizer. In a species like Kentucky bluegrass, which normally shows a long seed dormancy after harvest, it is also desirable to know if the 2,4–D treatments have any effects on dormancy.

MATERIALS AND METHODS

Varying amounts of 2,4-dichlorophenoxyacetic acid were mixed with separate 10-pound lots of complete 10–6–4 ($N–P_2O_5–K_2O$) fertilizer with the aid of a barrel-type concrete mixer. Weighed amounts of the mixtures of 2,4-D and fertilizer were then applied by hand over separate Kentucky bluegrass plots so as to apply 600 pounds of fertilizer per acre containing 0, 1½, 3, 6, and 9 pounds per acre, respectively, of 2,4-D. Plots 2 feet wide and 25 feet long with a 1 foot border were established on an area of Kentucky bluegrass sod heavily infested with narrow-leaved plantain, *Plantago lanceolata*. Each of five fertilizer and 2,4-D treat ments as well as a control (no fertilizer or 2,4-D) was assigned at random to the six plots of four replicate blocks. All treatments were applied on November 6, 1945.

The Kentucky bluegrass seed stalks and attached heads were harvested by hand on June 6, 1946, from individual plots. At this time the seed heads were mature and shattering of seeds was starting. The bundles of straw and seed heads were spread out on a bench in the greenhouse to dry for approximately 2 weeks, after which they were placed overnight in a constant temperature oven operated at 100° F. The seed heads were then rubbed by hand to remove the seeds.

The seeds[4] were cleaned on July 11, 1946, 36 days after harvest. A 3-gram sample was taken from those collected from each treatment and cleaned with an air-blast blower designed by Leggatt (4).

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[1]Contribution from the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md. Received for publication January 28, 1947.

[2]Physiologist, Assistant Botanist, and Senior Physiologist, respectively. Mr. John N. Yeatman assisted in conducting the seed germination experiments.

[3]Figures in parenthesis refer to "Literature Cited", p. 429.

[4]"Seeds" as used in this paper refers to the mature caryopsis with the enclosing lemma and palea.

There has been much research on the factors affecting the germination of freshly harvested seed of Kentucky bluegrass. In general, low temperatures, light, and a dilute solution of potassium nitrate aid in overcoming dormancy of fresh seed. Germination tests were made on the seed on July 15 and 16, 1946, 40 to 41 days after harvest. Each lot was then halved; one part was stored at room temperature and one part at constant 50°F and 50% humidity. The seed was stored under these two conditions because it has been shown in some species of fescue (3) that the dry storage of the dormant seeds at low temperatures prolonged the inability of the seeds to germinate at relatively high temperatures. Germination tests were made with the stored seeds on October 7 and 8, 1946, 124 to 125 days after harvest.

All the germination tests were made by placing 100 seeds each in Petri dishes on blotting paper moistened with either distilled water or a dilute solution of potassium nitrate. Tests were subjected to daily alternations of temperature between 15° and 25° C, 20° and 30° C, and 15° and 30° C. This daily alternation was secured by transferring the tests from one controlled unit to the other. The tests were held at the first of each alternate temperature for 16 hours each day, and at the second for 8 hours. The temperatures were maintained within 1° ±, except that in the 20° chamber the temperature dropped to 16° on the third and fourth days in the later tests. Seeds in all tests were exposed to light when at the higher of the alternate temperatures. The 30° germination unit was a glass-enclosed chamber in a north window. The tests at 25° were exposed to light for 30 minutes each morning by removing them from the constant-temperature chambers and placing them on the lawn on the north side of the laboratory building. Four tests were conducted at each temperature alternation, two with distilled water and two with potassium nitrate. A 0.2% solution of potassium nitrate was used in the 15° to 25° and the 20° to 30° alternations, and a 0.1% solution in the 15° to 30° alternation.

RESULTS

YIELD OF KENTUCKY BLUEGRASS SEED

The herbicidal effects of the various treatments on the vegetative growth of both grass and weeds have already been reported (6) in connection with other similar experiments. These results showed a very effective killing of narrow-leaved plantain even at the lowest rate of 2,4-D applied (1½ pounds per acre), and no apparent permanent ill effects of 2,4-D on established bluegrass plants even at the highest rate used (9 pounds per acre). At the time of seed harvest, narrow-leaved plantain present in both the unfertilized and the fertilized control plots had also produced an abundance of seed heads, whereas all plots that had received 2,4-D in the fertilizer mixture were almost entirely free of seed stalks of this weed. Occasional plantains that were present in plots treated with 1½ and 3 pounds per acre of 2,4-D were stunted in growth and failed to develop an appreciable number of seed heads. Plots that had received either 6 or 9 pounds per acre of of 2,4-D in the fertilizer were entirely free of plantain so that the pure stands of bluegrass seed stalks present in these plots were in sharp contrast with the control plots.

The data on yield of clean, heavy bluegrass seed from the various treatments are shown in Table 1. The plots that received 1½ or 3 pounds of 2,4-D per acre produced a significantly greater seed yield than either the fertilized or unfertilized controls. Plots that were treated with either 6 or 9 pounds per acre of 2,4-D in the fertilizer mixture produced a significantly greater seed yield than the unfertilized control but not significantly more or less than the fertilized control plots. The plots that received 6 to 9 pounds of 2,4-D per acre were entirely free of plantain seed.

TABLE 1.—*Yield and germination of Kentucky bluegrass seed produced on sod areas treated with dry applications of 2,4-D applied in a 10-6-4 fertilizer mixture.*

Treatment rate per acre, lbs.		Average yield of heavy seed, grams*	Percentage germination of seed†		
			Stored 40 days at room temperature and germinated 53 days	Stored 4 months and germinated 28 days at	
2,4-D	Fertilizer			Room temperature	50°F
0	0	3.1	83	87	86
0	600	10.7	79	89	88
1½	600	16.2	84	86	87
3	600	16.7	84	87	88
6	600	11.7	85	88	88
9	600	14.7	82	90	87

*Differences required for significance at the 5% level, 5.3 grams; at the 1% level, 7.3 grams.
†At 15° to 25°C alternation with potassium nitrate and light. Each value is the mean of eight tests. No significant differences between treatments.

GERMINATION OF KENTUCKY BLUEGRASS SEED

When the seed was tested 40 days after harvest extreme dormancy was evident. Germination was only well started at 28 days, at the time after-ripened seed has usually completed germination. Maximum germination occurred between the 28th and 42nd days. The tests were held for 53 days, when germination appeared complete at the most favorable condition, 15° to 25°C temperature alternation with potassium nitrate and light. There were no significant differences among the fertilizer and 2,4-D treatments (Table 1, column 4). An analysis of the 28-day results (not given) showed the field plot having no fertilizer and no 2,4-D to be significantly lower in percentage of germination than were the other treatments. This was evidently due to the greater dormancy of the seed from this plot since later tests at optimum germination conditions did not show a significant difference.

When tested for germination approximately 4 months after harvest, the seed from cold storage was somewhat dormant when tested at a condition unfavorable for dormant seed. When germinated at 20° to 30° C, seed held in cold storage showed 81.1% for the average of 2,4-D lots and 76.5% for the fertilized lot receiving no 2,4-D. This difference was significant. However, if the seeds were germinated at 15° to 25° C with light and potassium nitrate (the optimum condition of the several methods used) dormancy was not apparent and there were no significant differences among treatments within either storage condition or the means for both storage conditions.

DISCUSSION AND CONCLUSIONS

Under the conditions here described 2,4-D offers much promise as an aid in the production of grass seed free of contaminating weed seeds. Although the work was limited mainly to studies of but one weed species, *Plantago lanceolata*, and one crop, *Poa pratensis*, many other

serious farm weeds whose seeds frequently contaminate grass seed (8) likewise have been reported to be susceptible to the herbicidal effects of 2,4-D (1, 2). In addition, a number of the grasses such as fescue, redtop, rye grass, and orchard grass, commonly used in lawns, pastures, and other areas, have proved to be about as resistant to 2,4-D as Kentucky bluegrass. Established stands of bent grasses generally have been injured in varying degrees by 2,4-D treatments that have had no lasting ill effects on these more resistant grasses, except in the early seedling stages of development (7).

Plantain under the conditions of these experiments was very responsive to the fertilizer (no 2,4-D added) and produced an exceptional amount of leafy growth and an abundance of seed heads. This effect on the weed may have accentuated its competing effects on grass seed production in comparison with plots that received 2,4-D with fertilizer entirely free of weeds.

On the basis of the rather comprehensive seed germination tests that were made on the grass seed produced from the various treatments in this experiment it is concluded that 2,4-D applications to the soil had no adverse effects on the viability. It is of interest, however, that a measurable effect was found in the degree of seed dormancy. When tested at 20° to 30° C, a condition unfavorable for germinating non-after-ripened seed, germination was significantly higher for seed from plots treated with 2,4-D than from untreated plots. However, from a practical standpoint this effect of 2,4-D upon dormancy appears unimportant at this time.

The fertilizer plus 2,4-D mixtures were applied in late fall (November 6) at the time that the grass plants were becoming dormant. It is quite possible that similar treatments when applied to grass in other stages of development, such as at flowering time, may induce entirely different results with respect to grass seed production and viability.

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Sources of Resistance to Loose Smut, *Ustilago Nuda*, in Winter Barleys[1]

J. M. Poehlman[2]

THE following is a preliminary report on varietal resistance in winter barleys to the floral-infecting loose smut, *Ustilago-nuda* (Jens.) Rostr. This disease causes widespread damage in Missouri, and information on sources of resistance is needed to promote progress in breeding against it. The response of barley varieties reported herein was obtained with artificial inoculations.

METHODS AND MATERIALS

Two methods of artificial inoculation were employed. The partial vacuum technique as described by Moore (6)[3] was used in the spring of 1942. Inoculated seed was planted in the fall of 1942 and results reported as infection obtained in 1943. Because of its difficult operation, this technique was later discarded in favor of a simpler method in which a spore suspension is injected into the individual florets with a hypodermic needle. The latter method used in 1943 and later years, results reported for 1944 through 1946, has been described by Poehlman (7), but its essential features are repeated here.

The equipment consists of a hypodermic needle (1 inch, 25 gauge) inserted into a rubber bulb of 10-cc capacity. The bulb is filled with a suspension of chlamydospores by suction through the needle, and inoculations are made by injecting a few drops of this suspension into each floret of the barley spike within 1 to 2 days following pollination. At that time immature florets at the base of the spike are removed by clipping. The spore suspension is prepared by straining spores from smutted heads through a cheesecloth into tap water and adding dextrose to make a 1% solution.

Smutted heads collected from Missouri Early Beardless, Reno, Kentucky 1, Purdue 21, Ward, and similar varieties growing in experimental plots at Columbia were mixed and used in preparing inoculum for these studies. Seed of the above varieties had been obtained originally from commercial sources in Missouri, Oklahoma, Indiana, or Ohio. The physiologic races that may have been contained in this composite inoculum are unknown.

Three heads from each variety were inoculated in the field each year. Seed from each inoculated head was planted in a 1-foot row the following season. This dense planting rate was used since winter injury from heaving is severe in thinly spaced plantings of barley here. The percentage of smut reported for a variety in any season is the average percentage of smutted heads in the three individual rows. The total number of heads per individual row on which this percentage is based varied, but for the 1946 season it ranged from 8 to 51 with an average of 28 heads for all of the rows in which smut was found.

The 65 varieties and selections reported here include most of the standard varieties and several experimental strains currently being grown or tested in the winter barley areas of the United States. Seed of a few of these varieties and strains was obtained by the Missouri Experiment Station through commercial sources, but most of them came from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Also included are seven selections made at the Missouri Experiment Station from the variety Missouri Early Beardless. The winter barleys of foreign origin from the U. S. Dept. of Agriculture world collection are under test, but results are incomplete and will be reported later.

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[1]Contribution from the Department of Field Crops, University of Missouri, Columbia, Mo. Missouri College of Agriculture Journal Series No. 1036. Received for publication February 15, 1947.

[2]Assistant Professor of Field Crops.

[3]Figures in parenthesis refer to "Literature Cited", p. 436.

RESULTS

In presenting the data, varieties of winter barley included in these inoculation studies have been divided into five groups on the basis of origin and lemma appendage. Some inaccuracies may occur in this grouping since adequate information is not available for all varieties. In such cases varieties have been placed with the most probable group.

Percentages of infection are reported for the years 1943 through 1946. Only 16 of the varieties were inoculated in each of the 4 years. These include both highly resistant and highly susceptible varieties and serve as a guide to reliability of the inoculations. A few varieties are reported on the basis of 1 year's test where infection in that season was sufficient to indicate a susceptible reaction.

To facilitate the rating of varieties on the basis of resistance and susceptibility, the following ranges of infection have been arbitrarily established: 5% and under, resistant; 5.1% to 17, intermediate; and over 17%, susceptible. An analysis of variance of the 16 varieties that were inoculated in each of four consecutive years indicated that an average difference in infection of 12% is necessary to measure significant differences between varieties. The author believes that a variety which shows over 5% infection in these studies would be a doubtful source of resistance and thus suggests the above grouping. Shands and Schaller (8), in reporting inoculation results with spring barleys, gave special attention to varieties with less than 5% infection.

Table 1 presents the reaction of 22 rough-awned varieties and selections of Tennessee Winter or closely related origin. Within this group will be found the most winterhardy of barley varieties. Wintex and Randolph differ from the Tennessee Winter type in degree of hardiness and the origin of Fayette and New Mexico Winter is obscure (1, 9), but they are included in this group since they conform in many important features. Tenkow is of hybrid origin with Tennessee Winter as a parent (1, 9).

In this group of 22 varieties, 15 are classified as susceptible, 6 as intermediate, and 1 as resistant. Wisconsin Winter, Purdue 21, Tennessee Winter, and Reno are typical of the Tennessee Winter type. These varieties were inoculated in each of the 4 years and all are classified as susceptible. Fayette, Scottish Pearl, Michigan Winter, Ward, Kentucky 1, and Kentucky 2 are classified as intermediate, and Kentucky 6 as resistant. The results with Michigan Winter are in agreement with farm observations in Missouri, namely, that it is less susceptible to loose smut than Reno. The response of the Kentucky barleys is of interest since field observation of Kentucky 1 and Kentucky 2 in Missouri had indicated that these varieties are highly susceptible.

With artificial inoculation, Kentucky 1 contained 30.3% loose smut in 1943, but in the three succeeding years the highest infection obtained was 3.2% with an average infection for the 4-year period of 8.7%. Similar results were obtained with Kentucky 2. Kentucky 6 did not show any infection in the two years that it was inoculated.

TABLE 1.—*Reaction to loose smut, U. nuda, of rough-awned winter barley varieties and selections of Tennessee Winter or closely related origin.*

C. I. No.	Variety	Percentage infection				
		1943	1944	1945	1946	Av.
245	Fayette	—	8.5	0	29.2	12.6
277	Scottish Pearl	—	8.8	10.1	31.5	16.8
646	Tenkow	—	27.8	5.3	57.9	30.3
2036	Michigan Winter	8.1	17.0	—	—	12.6
2159	Wisconsin Winter	9.4	34.1	45.4	56.6	36.4
4581	Purdue 21	70.7	10.5	35.0	51.0	41.8
4582	Purdue 1101	67.8	—	—	—	67.8
4677	Kentucky 36	—	—	—	27.7	27.7
4678	Kentucky 6	—	—	0	0	0
6007	Ward	1.5	30.3	11.1	—	14.3
6034	Tennessee Winter	17.8	10.4	41.2	28.2	24.4
6050	Kentucky 1	30.3	0	3.2	1.4	8.7
6127	Wintex	—	31.5	—	44.9	38.2
6148	Kentucky 2	5.1	18.8	—	4.1	9.3
6372	Randolph	—	23.9	25.1	—	24.5
6377	Admire	19.8	35.9	—	27.4	27.7
6561	Reno	40.8	38.9	28.5	66.4	43.7
7033	Woodwin	—	53.3	23.1	58.7	45.0
7065	New Mexico Winter 1	—	—	—	35.3	35.3
7071	Mercer	71.5	26.7	—	—	49.1
7072	Ohio Winter 1	24.4	53.4	10.0	9.1	24.2
7075	Kirwin	—	25.1	36.4	3.4	21.6

The seed of the Kentucky 6 strain (C. I. 4678) was received by us in the winter barley classification nursery. Loose smut was observed in nursery rows of Kentucky 6 in 1946, but no check was made to determine whether it was *Ustilago nuda* or *U. nigra*. The reactions of the Kentucky strains suggest strongly that different physiologic races of *U. nuda* may have been used in these tests. Additional study on this point would be of value.

The response of eight smooth-awned winter barley varieties and selections is reported in Table 2. These varieties are of hybrid origin with a Tennessee Winter type barley as one of the parents (1, 9).[4] All of the barleys in this group are susceptible, except Kentucky 11 which is classified as intermediate. Kentucky 11 was tested in 2 years only and the amounts of infection varied widely. This reaction of Kentucky 11 is similar to the varied response of the rough-awned Kentucky strains.

The reaction of seven varieties of foreign origin are reported in Table 3. Esaw and Sunrise are included in this group since they are selections from Nakano Wase, a variety introduced from Japan, although they are believed to be field hybrids between Nakano Wase and unknown varieties (1). All of the varieties in this group are rough-awned except Sunrise and Wong which are awnleted. Bulgarian proved to be resistant, Alaska intermediate, and all other varieties

[4]Also personal correspondence with Mr. R. R. Mulvey, Indiana Agriculture Experiment Station, and Mr. David A. Reid, Kentucky Agriculture Experiment Station.

TABLE 2.—*Reaction to loose smut, U. nuda, of some smooth-awned winter barley varieties and selections.*

C. I. No.	Variety	Percentage infection				
		1943	1944	1945	1946	Av.
6021	Kentucky 11	—	—	0	26.0	13.0
6120	Marnobarb	23.8	42.3	—	33.3	33.1
6268	Smooth Awn 86	96.1	15.6	—	—	55.9
6562	Purdue 28156A3-2-2-2	74.8	—	—	—	74.8
6569	Jackson	44.5	39.2	13.3	—	32.3
7045	Jackson 1	4.7	47.4	48.5	21.3	30.5
7067	Purdue 28154A3-1-1-6	67.5	72.7	—	—	70.1
7119	Purdue 28154A3-1-1-6-2	—	—	23.0	59.1	41.1

TABLE 3.—*Reaction to loose smut, U. nuda, of some winter barleys of foreign origin.*

C. I. No.	Variety	Origin	Percentage infection				
			1943	1944	1945	1946	Av.
521	Bulgarian	Bulgaria	—	—	0	0	0
534	Alaska	Alaska	12.1	—	—	8.6	10.4
4690	Esaw (field hybrid)		—	7.3	33.8	—	20.6
6107	Olympia	Germany	—	34.7	15.4	58.4	36.2
6272	Sunrise (field hybrid)		—	21.4	—	—	21.4
6280	Poland	Poland	40.7	30.8	33.1	—	34.9
6728	Wong (hybrid)	China	—	55.2	11.3	—	33.3

susceptible. Low percentages of infection were obtained in the Alaska variety but none in Bulgarian in the 2 years these varieties were inoculated. Bulgarian is of moderate hardiness and winterkilling reduced the number of surviving plants in one of these years. Additional information should be obtained about this variety.

A recent source of new winter barley varieties has been the composite crosses of Harlan and Martini (2). Five varieties originating from these crosses were inoculated and the results are reported in Table 4. Texan and Nassau are smooth-awned barleys; the other three varieties of this group are rough-awned types. Santiam and

TABLE 4.—*Reaction to loose smut, U. nuda, of winter barley varieties selected from composite crosses.**

C. I. No.	Variety	Composite cross	Percentage infection				
			1943	1944	1945	1946	Av.
6367	Santiam	C. I. 5530	33.3	—	12.5	—	22.9
6373	Davidson	C. I. 5461	21.1	0	0	—	7.0
6499	Texan	C. I. 5530	—	—	—	14.4	14.4
6564	N. C. 11	C. I. 5461	69.2	—	—	—	69.2
7022	Nassau	C. I. 5530	—	12.1	0	12.3	8.1

*From Harlan and Martini (2).

North Carolina 11 were susceptible and Davidson, Nassau, and Texan were intermediate in these tests. Infection in Davidson in 1943 was 21.1%, but no infection was obtained in two later seasons. Middleton, *et al.* (4) reported Davidson to be highly resistant in artificial inoculation tests at the North Carolina Experiment Station. The response of this variety may be additional evidence of the presence of physiologic races of the loose smut organism.

In Table 5 is recorded the percentage infection of 23 hooded varieties and selections. Missouri Early Beardless, Tucker, and Missouri Early Beardless Selection No. B355 were susceptible; Tennessee Beardless 6, Tennessee Beardless 5, and North Carolina Hooded (C. I. 5951) were intermediate; the remaining 17 varieties and selections were resistant.

TABLE 5.—*Reaction to loose smut, U. nuda, of hooded winter barley varieties and selections*

C. I. No.	Variety	Percentage infection				
		1943	1944	1945	1946	Av.
2746	Tenn. Beardless 6	0	—	22.3	—	11.2
3384	Tenn. Beardless 5	—	12.8	—	—	12.8
5951	North Carolina Hooded	—	3.4	14.1	3.0	6.8
6051	Mo. Early Beardless	16.7	18.8	30.7	8.6	18.7
6235	Wood's Hooded	—	4.4	0	0	1.5
6477	Brugh 76	—	3.4	0	0	1.1
6491	Brugh 23	—	0	1.7	0	0.6
6563	Hooded 10	0	10.3	0	0	2.6
6571	Iredell	0	0	0	0	0
6574	Hooded 16	—	3.2	1.7	0	1.6
6998	Huga	—	0	0	—	0
7026	North Carolina 26	—	0	0	0	0
7038	York Hooded	—	—	0	0	0
7039	Tucker	—	28.5	23.6	18.0	23.4
7042	Clemson Hooded	0	5.6	0	—	1.9
7074	Marett Hooded 4	—	0	0	—	0
Mo. B350*	Sel. Mo. Early Beardless	0	0	0	0	0
Mo. B351*	Sel. Mo. Early Beardless	0	0	3.5	0	0.9
Mo. B355*	Sel. Mo. Early Beardless	31.9	47.3	8.4	61.4	37.3
Mo. B404*	Sel. Mo. Early Beardless	1.5	0	0	0	0.4
Mo. B405*	Sel. Mo. Early Beardless	—	2.3	0	0	0.8
Mo. B409*	Sel. Mo. Early Beardless	0	0	0	0	0
Mo. B411*	Sel. Mo. Early Beardless	0	0	0	0	0

*Accession number of the Missouri Agriculture Experiment Station.

Resistance in so many hooded winter types is of great interest, especially when consideration is given to their origin. Iredell, Hooded 10, Hooded 16, North Carolina 26, and Marett Hooded are all selections from one of the Tennessee Beardless forms, while Huga is of hybrid origin with Tennessee Beardless as one of its parents (1, 9). Aberg and Wiebe (1) lists Brugh 76 as a synonym for Tennessee Beardless 5 and York Hooded as a synonym for Tennessee Beardless 6, but their response is given separately here since infection in these

two varieties was lower than in the corresponding Tennessee Beardless type.

The exact origin of Woods Hooded, Brugh 23, and Clemson Hooded is not known, but it is probable that they too are of Tennessee Beardless origin. The Tennessee Beardless varieties in turn originated "by crossing Tennessee winter on a spring beardless type" (5). That many of these hooded types are resistant to *Ustilago nuda* has been generally known by southern barley experimenters. Middleton, *et al.* (4) have reported resistance in Iredell and North Carolina 26 with artificial inoculation, and Aberg and Wiebe (1) listed Hooded 16 as resistant.

Attention is also called to Missouri Early Beardless and the selections from it. Shands and Shaller (8) reported a high infection in this variety from artificial inoculation, and Livingston (3) used it as the susceptible variety in an inheritance study. Many selections from Missouri Early Beardless have been grown at the Missouri Experiment Station. It was early noted that these selections varied widely to infection from natural sources. The data reported here represent only a few of the lines that have been tested and were selected to show resistant lines as well as one susceptible line. These data confirm observations made from nursery rows that lines resistant to loose smut may be selected from the Missouri Early Beardless variety. The results observed are those that might be expected of a variety of this kind, for Missouri Early Beardless originated as a mass selection from a southern winter barley of unknown origin (1, 9).

DISCUSSION

The studies reported here were initiated to find the best sources of resistance to *Ustilage nuda* to use in a program of breeding winter hardy and disease-resistant barley varieties. It has been shown that 2 awned varieties and 17 hooded varieties and selections were resistant when artifically inoculated with a composite inoculum. Which of these resistant varieties and selections offers the most promise for breeding purposes?

The two awned varieties that proved to be resistant were inoculated only in two seasons. Little information is available about the infection these varieties show under heavy natural inoculation. It therefore appears that additional information should be obtained about their response. But in the hooded types abundant information is available, it seems, to warrant the immediate use of several of the many resistant forms in a breeding program. Iredell and North Carolina 26 have perhaps been most extensively tested, and, in addition to being highly resistant in extensive tests made by Middleton, *et al.* (4), were free of smut in the studies reported here. These two varieties are vigorous in growth and of good winterhardiness. In the latter characteristic they are superior to Marett Hooded, Huga, or Clemson Hooded and would therefore be more desirable as parental material in the northern winter barley growing area where winterhardiness is of paramount importance.

The selections from Missouri Early Beardless also appear to be desirable resistant material. Their hardiness in comparison with

Iredell and North Carolina 26 should be determined, since Missouri Early Beardless has been more winterhardy than Iredell or North Carolina 26 in the uniform hardiness nurseries. Limited data are available to show comparisons of four of these Missouri Early Beardless selections with Iredell and North Carolina 26 for the 4-year period 1943–46 at Columbia. The varieties and the average winter survival are as follows: B350, 84%; B351, 83%; B404, 84%; B405, 89%; Iredell, 75%; and North Carolina 26, 77%. In the same period the survival of Missouri Early Beardless was 80%, and that of Reno, another variety widely grown in Missouri, 91%. These data would indicate that the Missouri Early Beardless lines may be superior for breeding material from the standpoint of smut resistance and hardiness combined.

Although Iredell, North Carolina 26, and several of the Missouri Early Beardless selections are resistant to *Ustilago nuda*, they have all been susceptible at Columbia to other inportant barley diseases, including *U. nigra*, covered smut, scald, stripe, and spot blotch. Iredell has been partially resistant to powdery mildew as has North Carolina 26, and Missouri Early Beardless selections B351 and B405 have been resistant to this disease in the field.

Several of the Missouri Early Beardless selections have already been used in crosses at the Missouri Experiment Station. Selections from these crosses are now being increased and tested for yield and disease resistance. Several new high-yielding selections appear to carry resistance to loose smut and mildew. If these preliminary observations are borne out in later tests, we may have resistance to loose smut already transferred to highly productive varieties that will approach Reno in hardiness.

SUMMARY

The response of 65 winter barleys to artificial inoculation with *Ustilago nuda* during a 4-year period is reported here. Only 2 of 42 awned varieties were resistant, and these were tested in only 2 of the 4 years. The awned varieties included both rough and smooth selections of the Tennessee winter type, introductions from foreign countries, and selections from composite crosses. Seventeen hooded types were resistant out of 23 that were tested. All of the resistant hooded selections were from one of the Tennessee Beardless varieties or from Missouri Early Beardless.

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Notes

CRYPTIC HOMOZYGOUS LINES

IN an earlier paper in this JOURNAL (Vol. 37, pages 134–145, 1945), a plan was proposed for developing higher yielding hybrid corn. In brief, an established seed single cross was proposed as a constant tester and as the seed parent of commercial hybrids. Open-bred corn plants are to be selfed and crossed individually with the tester.

Let us look again at these open-bred plants. Each one is the product of two gametes. If each parent gamete came from a different homozygous line, the plant would be F_1 of the cross of two homozygous lines. Genetically it is equivalent to that. The test crosses then are actually double crosses. Each plant selfed and test crossed is F_1 of two cryptic homozygous lines and its progeny are the advanced generations of such a single cross.

The recombination of a selected number, e. g., 15, of the 1-year selfs is actually the recombination of 30 gametes or crytic homozygous lines carried to the second crossing to make a mixture of double crosses.

In 3 years altogether, we may in effect produce an entirely new series of strictly homozygous lines, combine them first into singles and the singles with an established tester single to make doubles, test the doubles one year, and recombine selected singles.

The earlier proposal was to take the recombination at the end of any 3-year cycle, or inbreds derived from it or from the group of selected 1-year selfs to make the pollinator for production fields. An alternative which may be feasible is to use advanced generations of just one of the selected 1-year selfs, or in effect advance generations of the single cross of two strictly homozygous lines.

The commercial "double cross" may then be slightly more uniform than those now used. Care will need to be exercised in choosing pollinators with tassels which shed good pollen abundantly. This selection must be done largely at the outset; not among the progeny of one of the 1-year selfs, for the latter type of selection may reduce specific combining ability with the tester. Grain production on pollen rows will of course be severely reduced below present yields with F_1 single cross pollinators.

Since my recent summary of the evidence for overdominance in yields of corn in this JOURNAL (Vol. 38, pages 1100–1103, 1946) I have seen the analyses of two additional sets of data.

Earl R. Leng has sent the analysis of data of C. M. Woodworth, Oren Bolin, and Leng on 7 inbred lines and the 21 F_1's. Paul H. Harvey has furnished data on 12 inbred lines and the 66 F_1's. Both seem to be in good agreement with almost all of the other sets in supporting the conclusion that the stronger inbred lines are worthless as testers for general combining ability. Regression of F_1 on the other parent line is essentially zero, or negative with strong testers. With the weaker lines of the several samples as testers regression is of the order of +0.60 and higher.

These results suggest that further improvement of yield of hybrid corn is likely to come largely by selection for specific combining

ability. They seem to me to suggest also that average yield or vigor of the parent lines of still higher yielding hybrids is likely to be less than the average of lines now being retained. If the tester single cross is made from strong lines, the pollen single cross may eventually involve lines so weak they can be handled only as "cryptics" seen only in an occasional F_1 plant and in its progeny.

Continuation of the proposed plan of breeding will provide the possibility of substituting an improved pollen single cross at the end of each 3-year cycle to be used with the same seed single cross.

For bisexual species, especially larger animals, the recombination of selected individuals after each cycle of test crossing may involve selections of both sexes. Alternatively, where reciprocal crosses may be impracticable and tested individuals all of one sex, full sibs of the opposite sex of those selected may be employed to effect the recombination. In these cases the entire recombined lot is likely to be needed for breeding stock to produce commercial hybrids by crossing with the tester line. The concept of just two cryptic homozygous lines combined into one stock for one side of the commercial hybrid is impossible; for just four lines it is probably impracticable. The concept of two cryptic homozygous parents of each individual tested can be entertained in consideration of breeding plans. Thus a wealth of material which is genetically equivalent to single crosses of homozygous lines is available for testing with any available inbred lines or single crosses of them which may seem suitable as testers.—FRED H. HULL, *Florida Agricultural Experiment Station, Gainesville, Fla.*

OBSERVATIONS ON METHODS OF INCREASING THE GERMINATION OF *PANICUM ANCEPS* MICHX. AND *PASPALUM NOTATUM* FLÜGGE

THESE observations were made in connection with various pilot tests at the Soil Conservation Service Nursery at Chapel Hill, N. C., to improve the germination of certain grasses which show promise in soil conservation work.

PANICUM ANCEPS, BEAKED PANICUM

This is a promising perennial, bunch-type summer grass, of the southern states adapted to moist bottomlands which are flooded occasionally. Despite the fact that 50 to 75% of its florets usually do not contain mature caryopses, it produces seed abundantly. Repeated efforts to establish this species by spring seeding have failed almost completely, but a satisfactory stand was obtained in the spring of 1944 from a rod-row planting made in September. In view of this, various attempts were made to treat the seed so that emergence could be secured from spring plantings, and some seed was sent to Boyce Thompson Institute, Yonkers, N. Y., for help on the problem. Recently, Garman and Barton[1] have reported approximately 100% germination of well-developed *Panicum anceps* seed after 8 weeks moist storage at 5° C. They also found that, "The germination capacity

[1]Contr. Boyce Thompson Inst., 14:117–122. 1946.

of pretreated seeds was not affected by drying in the laboratory for periods up to 1 month but was reduced more than one-half by drying as long as 2 months before planting".

The part of this note on *Panicum anceps* more or less supplements and verifies the findings of Garman and Barton. Table 1 gives the results of several treatments to improve the germination of *P. anceps*. It is conclusive that moist, cold storage of the seed for approximately 1½ months is highly effective in increasing the germination and that this stimulated effect is maintained in the seed for as long as 6 months when stored dry at ordinary room temperature. Merely scarifying the seed in sulfuric acid or with a disc scarifier[2] gave no significant improvement over no treatment. The seed tested had been recently harvested and passed through a seed blower. Microscopic examination of the samples showed that approximately 70% of the florets contained apparently mature and germinable seeds. At least duplicate samples of 50 seeds each of each treatment were planted in unsterilized fine sand in flats in the greenhouse and kept moist throughout the tests. This lot contained approximately 434,000 seeds per pound.

PASPALUM NOTATUM, BAHIA GRASS, PENSACOLA STRAIN

Paspalum notatum is one of the most promising pasture grasses of of the southeastern states and is being widely tested by pasture men and soil conservationists. Burton[3] has described six distinct strains of the species. He also reported[4] that sulfuric acid scarification was the best of several treatments to overcome the delayed germination normally characteristic of *P. notatum*.

Since sulfuric acid treatment is costly and difficult to apply, several methods of mechanical scarification were tested on various Bahia grass strains during the winter of 1943. The best results on the Pensacola strain are shown in the lower portion of Table 1. Like *Panicum anceps*, these seeds are relatively too light and their hulls too resistant to abrasion to permit satisfactory scarification by present mechanical means. There are about 220,000 seeds per pound, having an analysis of 95% mature caryopses. Although somewhat larger than *Panicum anceps*, the seeds are similar morphologically. It was found[5] that if treatment in a disc scarifier were continued for approximately 60 minutes at 1,150 r.p.m., a part of the fertile lemma of most seeds was removed and many seeds were entirely dehulled. Samples of these were planted, and only 2% of the partially dehulled seeds and none of the entirely dehulled ones germinated. The best commercial machine used in scarifying was one which blows the seeds violently against a rough metal surface. The best treatment in this machine perforated the hulls of less than half of the seeds, and the germination was not significantly better than untreated seeds. Seeds of the same lot gave 64% germination after they were stirred gently in concentrated technical sulfuric acid for 6 minutes.

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[2]Jour. Amer. Soc. Agron., 35:256–257. 1943.
[3]Jour. Amer. Soc. Agron., 38:273–281. 1946.
[4]Jour. Amer. Soc. Agron., 31:179–187. 1939.
[5]See footnote 2.

TABLE 1.—*Effect of various seed treatments upon the germination of Panicum anceps and Paspalum notatum planted in unsterilized fine sand in the greenhouse, 1943 and 1944.*

Treatment	Percentage germination after	
	2 weeks	4 weeks
Panicum anceps		
No treatment	0	0
Moist, cold storage:		
Stratified in damp Sphagnum moss at 7°C, 50 days	49	49
Conc. technical H_2SO_4, 6 minutes; stratified in damp Sphagnum moss at 7°C, 50 days	56	56
Soaked in 0.5% KNO_3, 24 hours, drained and stored damp at 5°C, 42 days	37	43
Soaked in 0.5% KNO_3, 24 hours, drained and stored damp at 5°C 42 days; subsequently dried rapidly and stored at room temperature for 6 months	66	66
Conc. technical H_2SO_4, 6 minutes*	2	6
Disc scarified 25 minutes at 1,150 r.p.m.	—†	3
Paspalum notatum		
No treatment	2	11
Disc scarified 30 minutes at 800 r.p.m.	20	25
One time through commercial scarifier set at 1,010 r.p.m.	2	29
Combine-harvested seed treated with Conc. technical H_2SO_4, 6 minutes*	64	76

*Seed gently stirred throughout treatment.
†No count made.

OTHER SPECIES

Less detailed observations on a few other paspalum species and other southern grasses have revealed that these species are characteristically slow to germinate, although they vary considerably in this respect. Fall planting of *Paspalum laeve*, field paspalum, on a large scale has given excellent germination in the spring as compared with practically none in spring seedings. Fall seeding of *Tripsacum dactyloides*, eastern gamagrass, also gave far better spring germination than spring seeding. Heavy spring volunteering has been observed repeatedly in old, clean-cultivated rod-row plots of *Paspalum dilatatum*, Dallis grass; *P. floridanum*, Florida paspalum; *P. notatum; P. urvillei*, Vaseygrass; and *Panicum anceps*.

Field observations on untreated seeds of *P. dilatatum*, *P. notatum*, and *P. urvillei* show that while they germinate much better than *P. laeve* and *Panicum anceps*, they do germinate slowly. It is probable also that a considerable percentage of the seeds of these species fail to germinate at all. Spring seeding of summer grasses is preferable to fall seeding, of course, since the seedlings grow off much better in freshly prepared soil.

From observations on these species, therefore, it would seem that a technique of moist, cold storage treatment prior to spring seeding might be a valuable substitute for acid treatment. It might also

improve the germination of those other species which germinate slowly but are commonly spring sown without pretreatment. It is believed that this matter deserves further study.

ACID SCARIFICATION

In connection with these observations, some points were noted in the technique of acid-treating small quantities of a few ounces of *Panicum anceps* and *Paspalum notatum* seeds, as follows: (a) The seeds should be thoroughly dry before treatment; (b) the treating container should be about 3 or 4 times the volume of the batch of seed; (c) the container should be placed in a water bath and kept cool while the seed-acid mixture is gently and continuously stirred throughout the process; and (d) after treatment, the seed-acid mixture should be emptied immediately into a large pan of fresh water and the acid washed out as rapidly as possible. It was observed also that most of the immature seeds immediately floated in water, whereas the mature ones sank to the bottom of the pan. However, if charring occurred during treatment, mature and immature seeds clumped together and floated. Continuous stirring helps keep the seed-acid mixture relatively cool during treatment and provides greater uniformity and a higher rate of scarification.

Microscopic examination of properly acid-treated seed shows that all glumes and sterile lemmas have been removed. In addition, a tiny opening about pin-point size occurs in the seed hull at the adaxial end of the fertile lemma near the embryo radicle, or the lemma is very thin at this point. Small openings may also occur at the abaxial tip of the seed, and considerable transverse etching of the hulls is common throughout the treated sample. These mechanical weakenings of the hull permit an easy entry of moisture to the caryopsis.—ANDREW C. MATHEWS, *U. S. Forest Service, Tifton, Ga.*

HEAD-HILL METHOD OF PLANTING HEAD SELECTIONS OF SMALL GRAINS

SEED from head selections of wheat and oats has been grown in hills rather than in head-rows as one of the steps of nursery procedure in the small grain breeding project at the Illinois Agricultural Experiment Station, Urbana, Ill., since 1941 (Fig. 1, A and B). Head-hill planting has proved to be a satisfactory technic and it is preferred to the head-row method.

Before planting, the field is furrowed out with a bean cultivator equipped with nine cultivator shovels so that 18 furrows are made each round. The furrows are about 3 inches deep and 1 foot apart (Fig. 1E). Planting head-hills in a furrow reduces winterkilling in winter wheat and it has also been observed that winterkilling is less in the head-hill than in the head-row.

A cotton cord with dyed sections spaced the same distance apart that the head-hills are to be planted was used as a guide for spacing the head-hills in the row (Fig. 1, D and E). The cord is stretched across the field on top of the ridge between the furrows. Each tenth

section of the cord was dyed a different color as an aid in laying out packages of seed. A cord dyed in three colors, so that each fifth and tenth section can be distinguished, has also been used.

Spacing between head-hills and groupings of head-hill rows has been varied. Eighteen or 24 inches between head-hills is satisfactory if the plants are to be grown to maturity. A single row or groups of two or three rows of head-hills with an alley between them have been used. In Fig. 1A, the rows of head-hills are in pairs.

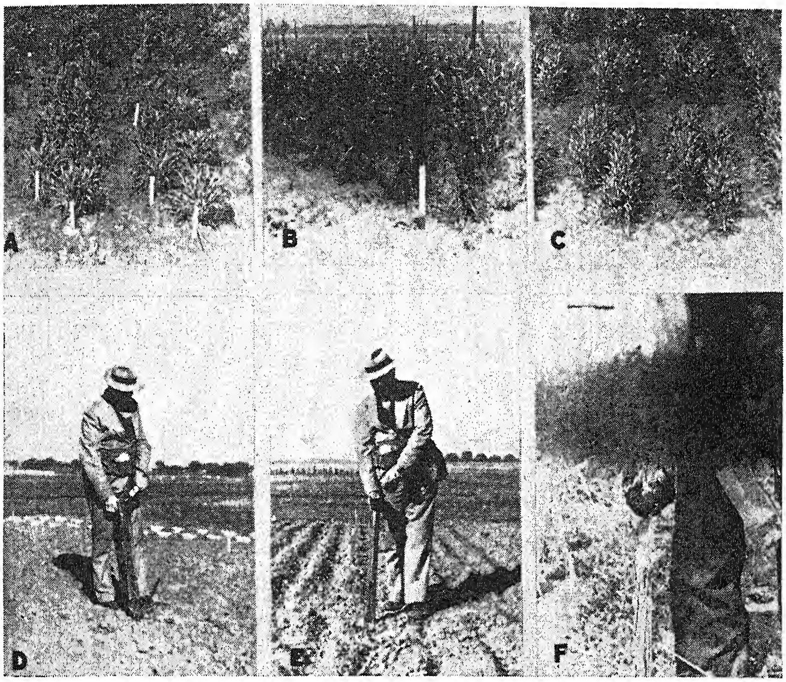

FIG. 1.—Photographs showing method of planting, arrangement, and harvesting head-hills. A, head-hills planted in a pair of rows; B, head-hills in a wheat mosaic disease nursery; C, paired 6-foot rows planted from seed produced by a head-hill; D and E, planting head-hills with a corn planter; F, stripping seed from oat head-hills.

When rows of head-hills were planted in groups of two or more the head-hills were staggered so that the head-hills in adjacent rows were not opposite each other (Fig. 1A). A staggered arrangement of head-hills in a pair of rows was obtained by stretching the dyed cord along the ridge between the pair of rows and planting the head-hills in the row to the left of the cord opposite the dyed sections, and the head-hills in the row to the right of the cord, half-way between the dyed sections.

Seed from individual heads of small grain may be threshed before planting or unthreshed heads may be dropped in the furrow and

covered. Threshed seed was planted with a hand corn planter (Fig. 1, D and E). Seed was poured into the corn planter and planted in hills in the furrow.

Planting head-hills with a corn planter can be done rapidly. In the spring of 1946, 7,494 head-hills of oats were planted in 34 man-hours or at the rate of 220 head-hills per man-hour. This time included distribution of seed, adjustment of dyed cords, and other necessary manipulations.

Less land is required for head-hills than for the same number of head-rows. For example, it takes 500 square feet for 100 head-rows, 3 feet long, spaced 1 foot apart with a 2-foot alley between the series. It takes 225 square feet for 100 head-hills, planted in pairs of rows 1 foot apart, with head-hills 18 inches apart in the row and a 2-foot alley between the pairs of head-hill rows. Thus the amount of land needed for an equal number of selections is reduced by more than one-half by the head-hill technic.

A direct comparison of plant development in head-hills and head-rows grown the same year has not been made. However, both methods were used in studies on physiologic races of loose smut of wheat. In 1943, 50 head-rows planted with an average of 17.5 seeds per head-row produced an average of 48 heads per head-row. In 1944, 50 head-hills planted with an average of 18.5 seeds per head-hill produced an average of 47.7 heads per head-hill. Data from the same five varieties of wheat were used in this comparison. These data indicate, if seasonal differences are disregarded, that plant development was about the same in both methods of planting.

Seed yield in head-hills has been satisfactory. Enough seed was produced for taking accurate notes on seed characteristics, but sufficient seed was not produced to run quality determinations and to plant the next crop. The usual practice has been to plant a pair of 6–foot rows from the seed produced from a head-hill (Fig. 1C).

It is much more convenient to study and to take notes on head-hills than on head-rows. Head-hills are spaced well apart and all of the heads are in a compact group so that it is easy to count or examine them. Ability to stand up was easy to judge since lodging in one head-hill does not affect other head-hills. Straw breaking due to hessian fly damage or to any other cause is easy to see. Because of the spacing and arrangement of head-hills, a head-hill planting can be studied more conveniently than can head-rows even during wet weather.

Harvesting head-hills is a simple process. When the grain has ripened to a stage where it could be cut with a binder, the head-hills are tied with binder twine and tagged. When the grain is ripe the head-hills are cut with a sickle. Oat head-hills, when ripe, can be stripped by hand, the grain together with the identification tag placed in a paper bag, and cleaned later (Fig. 1F).

The head-hill technic can be used for purposes other than that of growing selections at the beginning of a breeding cycle. It can be used as a means of purifying an old variety or a new selection. A large number of head-hills can be grown, the off-type head-hills removed, the remaining head-hills harvested, and the seed used as foundation seed for the first increase. A single head-hill will provide enough

plants to determine the reaction of selections and varieties to the rusts, smuts, wheat mosaic, and other diseases. It is being used as the method of planting in the study of physiologic races of loose smut of wheat. This method may be used whenever a small population of plants is sufficient, and individual plant data are not required.—O.T. BONNETT, *Illinois Agricultural Experiment Station*, and W. M. BEVER, *Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, Urbana, Ill.*

EFFECTS OF SPRAYING CEREALS WITH 2,4-DICHLORO-PHENOXYACETIC ACID

ONE of the important possibilities of 2,4-dichlorophenoxyacetic acid (2,4-D) has been its use as a selective spray in small grains. There is particular interest in such use for controlling certain of the "creeping" perennials. If a crop of grain can be realized while controlling these weeds, the cost of the control program would thus be greatly lessened.

In the work that has been reported the grain treated with 2,4-D had weeds present, and injury to the cereal crop by the chemical may have been compensated for by the reduced competition of weeds in the sprayed plots. The results of use of 2,4-D in cereals by many workers has been summarized.[1] The reported effects varied from (a) no effect on the cereal crop, (b) retardation in flowering of oats, (c) increase in yield, (d) great variability of grain yields of wheat when sprayed in the boot stage, and (e) definite injury to seedling oats. That injury to grasses may occur is indicated by Marth and Mitchell[2] who report a temporary depression in growth of lawn grass following spraying with 2,4-D.

If 2,4-D is to be used as a selective spray in cereals, information is needed as to the best time to spray the cereal crop. Such information can then be integrated with the most effective time of spraying the various species of weeds.

In 1946 spring wheat, oats, and barley were planted in nursery rows (four-row plots,rows 10 feet long, 1 foot apart) replicated four times. All plots were kept *free* from weeds throughout the experiment, and all plots were given three irrigations. Three different concentrations of 2, 4-D spray were applied at each of the three dates of treatment (0.10% solution omitted July 18), each plot in the experiment having been sprayed but once during the season. The spray concentrations used were 0.05%, 0.10%, and 0.15% solution of 2,4-D (1 part 2,4-D to 6½ parts "carbowax 1500") in water. The above spray solutions were applied at the rate of 250 gallons per acre, giving an application of 1, 2, and 3 pounds of parent acid per acre, respectively. Most recommendations for perennial weed control come within this range. The

[1]Proceedings of the Second Annual Meeting of the North Central States Weed Control Conference. St. Paul, Minn. 1945.

[2]MARTH, PAUL C., and MITCHELL, JOHN W. 2,4-dichlorophenoxyacetic acid as a differential herbicide. Bot. Gaz., 106:224–232. 1944.

———, ———. Effect of spray mixtures containing 2,4-dichlorophenoxyacetic acid, urea, and fermate on the growth of grass. Bot. Gaz., 107:417–424. 1946.

spray was applied with a 3-gallon knapsack sprayer, the nozzle of which was held high enough above the grain so that two rows might be sprayed at a time. Eight feet of each of the two center rows of each plot were harvested for yield.

Since the season at the Wyoming Experiment Station warms up much later than that of many other locations, the stage of development of the cereals at the time at which the spray was applied rather than date of treatment is of significance (Table 1).

TABLE 1.—*Yield, test weight, and height of weed-free Pilot spring wheat when sprayed with three concentrations of 2,4-D at three different dates at Laramie, Wyo.*

Date treated	Stage of development	Spray concentration, %*	Average yield, bu.	Yield rank	Test weight	Average height, in.
Check	———	No treatment	63.4	1	58.5	38.0
June 17	4–8 in. high, early jointing	0.05	55.5	3	58.5	38.0
		0.10	55.4	4	57.4	37.0
		0.15	43.1	6	56.8	37.9
July 1	12 in. high, early boot stage	0.05	40.9	7	53.5	37.5
		0.10	16.5	9	—†	36.5
		0.15	21.7	8	—†	36.0
July 18	Just heading to headed	0.05	57.3	2	58.7	38.0
		0.15	53.9	5	57.9	38.0
Standard error of the mean difference			4.8			

*Applied 250 gallon per acre, or 1, 2, and 3 pounds of 2,4-D per acre, respectively, for the different concentrations.
†Insufficient grain for test weight determinations; grain was badly shriveled.

As indicated in Table 1, the yields of spring wheat were depressed most by spraying at the early boot stage (July 1). All concentrations at this date gave yields which were significantly less than the untreated check. Reductions in yield were mostly due to the large amount of sterility which was evident in all plots sprayed in the boot stage, with the greatest sterility occurring in plots sprayed with 0.10% and 0.15% concentrations. The lower parts of the heads in many cases were fertile. The weight per bushel was also greatly decreased for plots treated in the boot stage. The 0.05% spray reduced the test weight by 5 pounds per bushel below that of the check. There was insufficient seed for test weight determinations on the plots sprayed with 0.10% and 0.15% solutions, but the grain appearance indicated that they were considerably lighter in weight than that of the plots sprayed with the 0.05% solution.

While yields of all plots treated at the early jointing and heading stages of growth were appreciably lower than those of the check plots, only the 0.15% concentration at the early jointing stage was significantly lower than that of the untreated check.

Distinct growth abnormalities were evident in plots treated at the early jointing stage. Some sterility was evident in all these plots, with the greater sterility at the higher concentrations. Many spike ab-

normalities were observed in plots treated at the early jointing stage, such as the two outer glumes of a spikelet grown together, lemmas of two adjacent florets grown together enclosing the two caryopsis (if developed) and palea, and two spikelets per rachis joint (opposite sides of rachis, as well as twins on the same side).

The plots treated at the heading stage of growth had a more nearly normal appearance than those treated at other dates. Very slight chlorosis, with a slight curvature of the second and third nodes, but no head abnormalities were present in plots treated at the heading stage. The untreated check plots had normal appearance.

Blackbirds damaged the oat and barley plots so severely that yield data are not reliable. The appearance of the barley experiment would indicate that yield results might follow the same general trend found in the spring wheat.

The most striking response in barley was observed in plots sprayed in the late boot stage. The day following treatment the plants had the appearance of severe lodging. These plants never fully recovered. A high percentage of sterility in the heads was evident in all plots treated at this time. The height of the plants treated in the boot stage averaged 7 inches shorter than the check.

The barley plots sprayed at the jointing stage of growth had some twinning in the heads (four to five florets per rachis node.) There was slight chlorosis early, but the plants appeared to recover fully. The plots sprayed when fully headed appeared more nearly normal than that of the plots sprayed at the other dates.

The oat plots treated with 2,4-D showed less striking contrasts in appearance than that found in either barley or spring wheat. The plots treated in the prejoint stage gave the greatest visible response. The upper leaves were rolled and stiff, the color was darker green, and the plants were slightly shorter than in the other treatments. The general appearance of the other plots was approximately normal.

Under the conditions of these experiments, the following conclusions were reached:

(1) Treating cereals when *Weed-free* with 2,4-D gave reductions in yield as compared with the untreated check plots. If applied at or before jointing or after the heading stages of growth, as much as 3 pounds of 2,4-D per acre (0.15% solution at 250 gallon per acre) may be sprayed for weed control in spring wheat and barley and still get a fair grain yield. (2) Spraying spring wheat and barley in the boot stage significantly depressed yields as compared with the untreated check. Treating in the boot stage caused many sterile heads. (3) Greatest head abnormalities (other than sterility) of wheat and barley occurred in plants sprayed at or before the jointing stage. (4) The 1-pound rate of application (0.05%) gave the highest yields of all the treated plots at all dates of application. Significant reductions in yield were obtained in all the treatments at the boot stage of growth and at the 3-pound rate (0.15%) applied at jointing.—DAYTON L. KLINGMAN, *Department of Agronomy and Agricultural Economics, Wyoming Agricultural Experiment Station, Laramie, Wyo.*

Book Review

THE NATURE AND PREVENTION OF THE CEREAL RUSTS AS EXEMPLIFIED IN THE LEAF RUST OF WHEAT

By K. Starr Chester. Waltham, Mass.: The Chronica Botanica Co.; New York: Stechert-Hafner, Inc. XVI+269 pages, illus. 1946. $5.

THIS book is primarily a monographic treatment of *Puccinia triticina*, the leaf rust of wheat. Although reference is made to historical accounts of rust from biblical times to recent periods, the main portion of the text summarizes the results of research during the past 25 years. The author believes the importance of leaf rust has been overlooked in the past and states "*Puccinia triticina* occupies the notorious position of being the foremost pathogen of the world's foremost food crop." Many who have worked with stem rust will undoubtedly question this statement.

The author cites several observations that suggest the intriguing possibility that rusts may have the capacity to fix atmospheric nitrogen. The life cycle of leaf rust is outlined and evidence presented to show that in many areas conditions usually favor year around infection of wheat by uredospores or dormant mycelium. Thus *Thalictrum* spp. though readily infected artifically with basidiospores of *P. triticina* probably rarely function naturally as alternate host for the rust. This suggests that new races of leaf rust originate by mutation rather than by a sexual phase. In eastern Siberia an entirely different situation exists. Here, basidispores of leaf rust regularly and naturally infect *Isopyrum fumarioides* which functions as the alternate host.

Concepts of physiologic specialization are discussed along with present refinements of the differential host technic. Factors influencing host and fungus in race determinations are considered. The author cites evidence that plant breeders need not be concerned with the many individual physiologic races of leaf rust but rather with the fewer race groups.

Data are presented which show little correlation between the amount of rust in the fall and that of the following spring. The earliest period when temperature and moisture approximate the optimum for multiplication of over-wintered rust is termed the "critical month". This period determines the extent of the epiphytotic to follow. Weather during the remainder of the growing season is usually poorly correlated with rust development.

Dusting leaf rust with sulfur is considered a possible practical control measure. Of particular interest under the discussion of the morphological and physiological basis for resistance are the investigations of phenolic compounds with respect to rust resistance and the role of specific proteins in rust resistance or susceptibility.

The last chapter deals with breeding for resistance. Reference is made to reports of crosses among different species of *Triticum* as well

as standard methods of crossing and selecting. A portion of the chapter lists the history of development of leaf rust resistant wheats in the United States and other countries.

An extensive bibliography including numerous Russian papers which have been translated is a valuable feature of the book.—K. W. KREITLOW.

Agronomic Affairs

CALL FOR PAPERS FOR CROP SCIENCE DIVISION

MEMBERS of the Crops Science Division wishing to present papers at the American Society of Agronomy meetings at Cincinnati, November 18 to 21, 1947, are requested to submit titles to the Division chairman as soon as possible but not later than July 1.

Information to be submitted with the title should include time desired for presentation and a brief description of contents of the paper or a suggestion of the Section in which it should be included.

Address all communications regarding the meetings of the Crops Science Division to Doctor W. M. Myers, Chairman, U. S. Regional Pasture Research Laboratory, State College, Pa.

A STATISTICAL SCHOOL

STATISTICIANS and those interested in statistics from the United States and foreign countries will convene at Virginia Polytechnic Institute, Blacksburg, Va., for the statistical summer session, August 5 to September 5.

This summer statistical session is being sponsored jointly by Virginia Polytechnic Institute, University of North Carolina, University of Michigan, Iowa State College, and the Federal Bureau of Agricultural Economics.

The faculty will consist of Walter A. Hendricks, U. S. Dept. of Agriculture; Renis Likert, University of Michigan; H. L. Lucas, University of North Carolina; Maurice G. Kendall, England; George W. Snedecor, Iowa State College; Frank Yates, Rothamsted Experiment Station, England; Earl E. Houseman, U. S. Dept. of Agriculture; Raymond J. Jessen, Iowa State College; Churchill Eisenhart, Chief of Statistical Engineering Section, Bureau of Standards, formerly with the University of Wisconsin; and Boyd Harshbarger, Virginia Polytechnic Institute.

The following courses will be offered for credit: Engineering Statistics; Statistical Methods; Design and Animal Experiments; Schedule Design and Interview Techniques for Sample Surveys; Sampling Design and Analysis; Mathematical Theory of Sampling; Seminar; Mathematical Statistics, and Experimental Design.

In addition to the faculty, probable seminar speakers are W. F. Callendar, W. G. Cochran, Miss Gertrude M. Cox, W. E. Deming, George Gallup, Maurice Hansen, Harold Hotelling, Arnold King, and Charles F. Sarle.

Inquiries regarding the summer session should be addressed to Boyd Harshbarger, Professor of Statistics, Statistical Summer Session, Virginia Polytechnic Institute, Blacksburg, Va.

NEWS ITEMS

VILAS T. WALHOOD has been named Assistant in Agronomy in the North Dakota Agricultural Experiment Station and assigned to the corn breeding program.

A. J. LEJEUNE of the Department of Plant Science of the University of Manitoba has been named Assistant Professor of Agronomy in the School of Agriculture, and Assistant Agronomist in the Experiment Station, North Dakota Agricultural College, Fargo, N. D. Mr. Lejeune has worked with Dr. P. J. Olson of the University of Manitoba, upon the genetics of the barley plant, and has been assigned to barley breeding investigations in North Dakota.

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RALPH W. SMITH, Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, who served the Bureau and the North Dakota Agricultural Experiment Station in a cooperative capacity at the Branch Agricultural Experiment Station at Dickinson, N. D., retired October 31, 1946, after 32 years of service at that Station where he was in charge of wheat, corn, oats, barley, and flax variety and breeding problems.

—A—

THE 1947 NORTH DAKOTA LEGISLATURE appropriated funds for the erection of storage and processing facilities for the corn breeding program and additional greenhouses at the Experiment Station at Fargo. Funds were also appropriated for a seedhouse and equipment and additional land at the North Central Experiment Station and State Seed Farm at Minot, N. D.

—A—

CLEMSON AGRICULTURAL COLLEGE has established a graduate school and is this year offering graduate courses for the first time in its history. The master's degree may now be obtained in agronomy at Clemson and plans are being made to give the doctor's degree.

—A—

A FOUNDATION OF APPLIED RESEARCH situated near San Antonio, Texas, on a 3,000-acre tract of fertile prairie land was opened on April 6th. The project combines an industrial research laboratory and a program of research covering agriculture, the natural sciences, and medicine. The Foundation is endowed by gifts of valuable oil property by Tom B. Slick.

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ACCORDING to recent newspaper accounts, Doctor Selman A. Waksman of the New Jersey Agricultural Experiment Station at New Brunswick will receive the $5,000 Passano Foundation award for his discovery of streptomycin at the meeting of the American Medical Association in Atlantic City in June.

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THE DUPONT COMPANY has announced the appointment of Doctor M. F. Gribbins as a member of the Technical Service Section of the Ammonia Department to be concerned principally with development work relating to fertilizers and dairy and cattle feeds.

DOCTOR RUSSELL COLEMAN has been named Acting Director of the Mississippi Agricultural Experiment Station, State College, Miss., to take the place of the late Doctor Clarence Dorman, who died suddenly from a heart attack on February 9, 1946. Doctor Coleman has been Associate Director of the Station since January 15, 1946, and was Associate Professor of Soils prior to this appointment.

—A—

DOCTOR J. E. ADAMS, formerly Superintendent of the Delta Branch Experiment Station, Stoneville, Miss., has been named Head of the Department of Agronomy of the Texas Agricultural Experiment Station, College Station, Texas.

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A TWO-REEL sound motion picture entitled "Death to Weeds" has been produced for the Dow Chemical Company and is available without charge for showings to interested groups. The film deals with the latest methods of weed prevention and destruction in all areas where they reduce agricultural production. For details about the film and its availability, write to Mr. Millard Hooker, Dow Chemical Company, Midland, Michigan.

—A—

DOCTOR GILBEART H. COLLINGS, Professor of Agronomy and Soils at the Clemson Agricultural College, Clemson, S. C., has been elected President of the South Carolina Academy of Science for the year 1947–48.

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"DEVELOPING VILLAGE INDIA" is the title of a well-illustrated monograph from the Imperial Council of Agricultural Research, New Delhi, India. The publication was issued as a special number of *Indian Farming*. A comprehensive picture of Indian agriculture is presented from the standpoint of community effort. In addition, the treatise deals with many aspects of the political, social, economic, and recreational activities of the Indian village. Apparently, it is an attempt to interpret Indian community life to the outside world, particularly the occidental world, and affords an abundance of factual background information on India's struggle to establish herself as a political and economic entity.

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A Comparison of Variance Components in Corn Yield Trials: I. Error, Tester×Line, and Line Components in Top-Cross Experiments[1]

W. T. FEDERER AND G. F. SPRAGUE[2]

THE procedures used in conducting corn yield trials have become fairly well standardized. The early studies of Bryan (2)[3] had an important bearing in determining plot size and shape. More recently, studies by Cochran (4) have provided some measure of the efficiency of the newer lattice designs in corn yield trials. Definite opinions are held by various workers but little concrete evidence is available bearing on the most efficient distribution of a given number of plots with respect to replicates, locations, number of testers, etc. A comparison of the relative magnitude of variance components should provide approximate answers to such problems. This paper will be devoted to the evaluation of error, tester×line, and line components of variance in a series of top-cross experiments.

The utilization of hybrid vigor in either plant or animal breeding requires the evaluation of inbred lines in hybrid combinations. Jenkins (7) and others have demonstrated a general correlation between vigor and certain other characters in the inbred lines and the yield of their crosses. In general, however, these associations were too small to be of much value in selection. The merits of each line can be determined most efficiently by actual comparisons of the hybrid combinations.

Lines can be tested in a series of single crosses, but this limits the number of lines which may be tested. For example, all possible combinations of 50 lines would require the making and testing of 1,225 single crosses which is impractical. A more simple procedure is to make top-cross tests. This method is widely used at the present time particularly in the first evaluation of new lines. The better lines from

[1]Contribution from the Statistical Laboratory and the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, and the Bureau of Agricultural Economics and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating. Journal paper No. J-1379 Projects 890 and 163. Received for publication January 6, 1947.

[2]Associate Agricultural Statistician Bureau of Agricultural Economics, and Senior Agronomist, Bureau of Plant Industry, Soils, and Agricultural Engineering, collaborators with the Iowa Agricultural Experiment Station, respectively. For their helpful suggestions and criticisms the writers extend their thanks to W. G. Cochran, A. M. Mood, and to the others who reviewed this paper.

[3]Figures in parenthesis refer to "Literature Cited", p. 463.

these preliminary comparisons then are subjected to more detailed testing in single and double crosses to determine the specific combinations best suited to different situations.

At the present time many of the corn top-cross tests are made using only one tester. This tester parent may be a single cross, double cross, or an open-pollinated variety. When it is desired to replace one of the inbred lines in a particular double-cross combination, the use of the opposing single cross as the tester parent is probably adequate. However, when the new lines are to be used in a number of combinations, it would seem desirable to have a more complete knowledge of the general combining ability of the line. In this case the use of only one single cross as a tester may be rather inefficient.

To answer the question as to the relative number of testers required, a statistical study was conducted using 11 experiments grown in Iowa from 1940 to 1942 which involved varying numbers of lines, testers, and replicates. These experiments were used to obtain estimates of the error, tester×line, and line components of variance which in turn were used to indicate the efficiency of varying the number of testers, lines, and replicates in experiments designed to measure combining ability.

Components of variance have been used in the study of a number of problems. Cochran (3) has discussed the situation where a replicated field trial involving a particular set of treatments is conducted at a number of locations in one year or at the same location over a number of years. His interest was in the estimation of treatment response and the test of significance of the treatment×location interaction when the individual error mean squares were not assumed to be homogenous. The data available for this study present a somewhat similar problem. The components to be estimated are different but essentially the same procedures can be used. Crump (5) has cited a number of additional papers dealing with estimation of variance components and has given a method for calculating the standard errors of the individual components.

AVERAGE VALUES OF MEAN SQUARES

The 11 top-cross experiments were divided into two groups on the basis of the field designs used. The first group consisted of randomized blocks and the second group split-plot designs. The various experiments were made up of r replicates (3 to 6), t testers (2 to 3), and l lines (6 to 98). The analysis and average mean squares for the randomized design are given in Table 1 and for the split-plot design in Table 2.

The average values in repeated samples of mean squares (Table 1) are obtained from the following equation which represents the yield of the i^{th} line crossed on the j^{th} tester in the k^{th} replicate:

(i) $x_{ijk} = \mu + \lambda_i + \tau_j + \rho_k + (\lambda\tau)_{ij} + (\lambda\rho)_{ik} + (\tau\rho)_{jk} + \epsilon_{ijk}$

This formula assumes that x_{ijk} is normally and independently distributed. μ represents the experiment mean, λ_i the effect of the i^{th} line, τ_j the effect of the j^{th} tester, ρ_k the effect of the k^{th} replicate, $(\lambda\tau)_{ij}$ the interaction of the i_{th} line and the j_{th} tester, $(\lambda\rho)_{ik}$ the inter-

TABLE 1.—*Analysis and average mean squares of a randomized complete blocks design.*

Source of variation	Degrees of freedom	Average value of mean squares	Estimates of average values of mean squares
Replicates	$r-1$		
Testers	$t-1$		
Lines	$l-1$	$\sigma^2_E+r\sigma^2_{LT}+t\sigma^2_{LR}+rt\sigma^2_L$	$s^2_E+rs^2_{LT}+ts^2_{LR}+rts^2_L$
Replicates × testers	$(r-1)(t-1)$		
Replicates × lines	$(r-1)(l-1)$	$\sigma^2_E+t\sigma^2_{LR}$	$s^2_E+ts^2_{LR}$
Lines × testers	$(t-1)(l-1)$	$\sigma^2_E+r\sigma^2_{LT}$	$s^2_E+rs^2_{LT}$
Replicates × line × testers	$(r-1)(l-1)(t-1)$	σ^2_E	s^2_E
Total	$rlt-1$	Total variance	

TABLE 2.—*Analysis and average mean squares for the split-plot design.*

Source of variation	Degrees of freedom	Average value of mean squares	Estimates of average values of mean squares
Replicates	$r-1$		
Testers	$t-1$		
Error (a)	$(r-1)(t-1)$		
Lines	$(l-1)$	$\sigma^2_E+r\sigma^2_{LT}+rt\sigma^2_L$	$s^2_E+rs^2_{LT}+rts^2_L$
Lines × testers	$(l-1)(t-1)$	$\sigma^2_E+r\sigma^2_{LT}$	$s^2_E+rs^2_{LT}$
Error (b)	$t(r-1)(l-1)$	σ^2_E	s^2_E
Total	$rlt-1$	Total variance	

action of the i^{th} line and the k^{th} replicate, $(\tau\rho)_{jk}$ the interaction of the j^{th} tester and the k^{th} replicate, and ϵ_{ijk} is the interaction of the i^{th} line on the j^{th} tester in the k^{th} replicate. Since we are interested in estimating components rather than tests of significance, the L×R component is segregated from the error component. It may be assumed that the lines, replicates, and testers involved in the experiments were random samples of their respective categories.

For the split-plot analysis in Table 2 the average values of the mean squares are obtained from the following equation:
(ii) $x_{ijk}=\mu+\lambda_i+\tau_j+\rho_k+(\lambda\tau)_{ij}+(\tau\rho)_{jk}+\epsilon_{ijk}$, where the elements of the equations are the same as in equation (i) except that the ϵ_{ijk} effect is a composite of the ϵ_{ijk} and the $(\lambda\rho)_{ik}$ of the randomized blocks design. This condition then changes the average value of the line mean square, i.e., the line mean square for the split-plot design is made up of three components of variance while that for the randomized complete blocks design contains four components of variance. It is not possible to segregate the L×R component in the split-plot design as this is confounded with the L×T×R component. The replicates, lines, and testers are considered to be random samples of possible replicates, lines, and testers, respectively. In both equations (i) and (ii), μ is considered as a parameter while the remainder are considered as independent random variables.

EXPERIMENTAL DATA

The mean squares and variance components for error, lines× replicates, lines×testers, and lines from the 11 top-cross experiments are presented in Table 3. The tests were conducted during 1940–42 (column 1) in different locations and varied with regard to number of lines (column 11, d.f.+1), number of replicates (column 12), and number of testers (column 13). The mean squares for the different sources of variation and their respective degrees of freedom are presented in columns 4 to 11. From the formulas given in Tables 1 and 2 it is possible to solve for the components of variance given in Table 3 (columns 4, 14, 15, and 16). The formulas given in Table 1 (randomized blocks design) were used to estimate the components in the upper part of Table 3 and the formulas in Table 2 (split-plot design) for the values in the lower part of Table 3. The symbols r_i denote the number of replicates, t_i the number of testers, and l_i the number of lines in the i^{th} experiments. s^2_{Ei} denotes the error component, s^2_{LTi} the line×tester interaction component, and s^2_{Li} the line component in the i^{th} experiment.

An illustration of the method used in calculating the component estimates is presented in Table 3, using the data from experiment 14 (1940) as presented in the first line of Table 4, as follows:

Source of variation	Degrees of freedom	Mean square	Estimates of components of variance
Lines	38	65.34	$s^2_L=\dfrac{65.34-4.08-6.08+413}{10}=5.931$

Source of variation	Degrees of freedom	Mean square	Estimates of components of variance
Replicate × lines	152	4.08	$s^2_{LR}=\frac{4.08-4.13}{2}=-0.025$
Lines × testers	38	6.08	$s^2_{LT}=\frac{6.08-4.13}{5}=0.390$
Reps. × lines × testers	152	4.13	$s^2_E=4.13$

In this study it has been assumed that the several components will vary from experiment to experiment and hence the estimates of σ^2_{Ei}, σ^2_{LTi}, σ^2_{Li}, and the ratios $\sigma^2_{Li}/\sigma^2_{Ei}$ and $\sigma^2_{LTi}/\sigma^2_{Ei}$ need not be constant.

The nature of the data used, i.e. different lines and testers compared in different locations and in different years, might well be expected to yield heterogeneous error variances. The data support this assumption. Bartlett's (1) test for the homogeneity of variances yields a highly significant χ^2 for both the split-plot and randomized blocks designs.

Approximate tests (3,5) assuming normally distributed variates of the line × tester(s^2_{LTi}) and the line (s^2_{Li}) components of variance gave highly significant results indicating a lack of homogeniety. It seems reasonable to suppose that both σ^2_{LTi} and σ^2_{Li} would vary in different experiments. For example, a sample of lines from an open-pollinated variety might be expected to be more variable than an equal sized sample of lines from a high yielding F_2 population.

Some comparison of σ^2_{LT} and σ^2_L with σ^2_E is necessary and the ratio appears to be most appropriate. This could be done in two ways, (a) estimate the components from each individual experiment and use the ratio of the totals or averages, or (b) obtain ratios from each experiment and obtain some form of average of the ratios. The second procedure has been used. The individual estimates have been combined as an unweighted arithmetic average.

The average value of the ratio $E\left[\frac{s^2_{Ei}+r_i s^2_{LTi}}{r_i s^2_{Ei}}-\frac{1}{r_i}\right]=E\left[\frac{s^2_{LTi}}{s^2_{Ei}}\right]$ is not an estimate of a common ratio but rather is an estimate of the ratio for the i^{th} experiment. The same is true for the ratio of the line and error variance components, $E\left[\frac{s^2_{Ei}+r_i s^2_{LTi}+r_it_i s^2_{Li}}{r_it_i s^2_{Ei}}-\frac{s^2_{Ei}+r_i s^2_{LTi}}{r_it_i s^2_{Ei}}\right]=$ $E\left[\frac{s^2_{Li}}{s^2_{Ei}}\right]$. Therefore s^2_{LTi}/s^2_{Ei} is not an unbiased estimate of $\sigma^2_{LTi}/\sigma^2_{Ei}$.

An unbiased estimate of $\sigma^2_{LTi}/\sigma^2_{Ei}$ equal to α_i is (for both the randomized blocks and split-plot designs)

(iii) $\hat{a}_i=\frac{N_{Ei}-2}{N_{Ei}}\left[\frac{s^2_{LTi}}{s^2_{Ei}}-\frac{2}{r_i(N_{Ei}-2)}\right]$, where N_{Ei} is the error degrees of freedom in the i^{th} experiment. For the ratio of the line and error components of variance, an unbiased estimate of $\sigma^2_{Li}/\sigma^2_{Ei}=\gamma'_i$ from the

TABLE 3.—*Data from 11 corn top-cross experiments involving more than one tester.*

Year	Expt. No.	Kinds of testers*	Sources of variation								No. of replicates = r_i	No. of testers = t_i	Components of variance			Unbiased estimates of the ratio of variance components	
			s^2_{Ei} = replicate × line × tester		Line × replicate		Line × tester		Line								
			Mean	d.f.†	Mean square	d.f.	Mean square	d.f.	Mean square	d.f.			s^2_{LTi}	s^2_{LRi}	s^2_{Li}	$\hat{a}_i$‡	$\hat{c}_i$§
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Randomized Complete Blocks Designs																	
1940	14	S.C.	4.13	152	4.08	152	6.08	38	65.34	38	5	2	0.390	−0.025	5.931	0.091	1.418
	15	S.C.	5.11	66	9.29	66	8.84	22	25.67	22	4	2	0.932	2.090	1.581	0.169	0.304
	16	S.C.	3.97	20	3.96	20	8.76	5	42.22	5	5	2	0.958	−0.005	3.347	0.197	0.769
	17	S.C.	1.50	36	3.99	36	4.32	9	23.09	9	5	2	0.564	1.245	1.628	0.344	1.031
1941	1	D.C.	3.82	138	4.60	138	8.00	69	16.41	69	3	2	1.393	0.390	1.272	0.355	0.331
	2	D.C.	5.80	160	11.08	160	7.24	80	20.57	80	3	2	0.480	2.640	1.342	0.078	0.231
	3	D.C.	2.54	16	2.04	16	4.37	8	4.19	8	3	2	0.610	−0.250	0.053	0.168	0.039
	4	D.C.	4.39	28	5.78	28	6.42	14	19.99	14	3	2	0.677	0.695	2.030	0.119	0.441
Average of 8 experiments																0.190	0.570
Split-plot Designs																	
1940	1	S.C.	9.19	693	—	—	19.16	154	32.01	78	4	3	2.492	—	1.071	0.270	0.116
	45	S.C.	6.95	126	—	—	20.66	42	125.98	21	3	3	4.570	—	11.702	0.642	1.657
1942	8 & 9	S.C.	9.84	970	—	—	15.22	97	23.68	97	6	2	0.897	—	0.705	0.091	0.071
Average of 3 experiments																0.336	0.615
Average of 11 experiments																0.229	0.583

*S.C. = Single cross testers; D.C. = double cross testers.
†d.f. = Degrees of freedom.
‡Estimates of $\sigma^2_{LTi}/\sigma^2_{Ei}$.
§Estimates of $\sigma^2_{Li}/\sigma^2_{Ei}$.

split-plot design is (iv) $\hat{c}'_i = \frac{N_{Ei}-2}{N_{Ei}}\left[\frac{s^2_{Li}}{s^2_{Ei}}\right]$.

From the randomized block design the appropriate formula is (v) $\hat{c}_i = \frac{N_{Ei}-2}{N_{Ei}}\left[\frac{s^2_{Li}}{s^2_{Ei}} + \frac{2}{r_i t_i (N_{Ei}-2)}\right]$, where N_{Ei} is the error degrees of freedom in the i^{th} experiment.

The unbiased estimate of α_i ($\hat{a}_i$) is given in column 17 of Table 3. $\hat{c}_i$ which is an unbiased estimate of γ_i is presented in the last column of the upper part of Table 3. $\hat{c}_i'$, an unbiased estimate of γ_i', is presented in the bottom part of the last column of Table 3. Since the variation in $\hat{a}_i$ and $\hat{c}_i$ from experiment to experiment cannot be attributed to sampling error the best estimate would seem to be the unweighted means $\bar{a} = \frac{\Sigma\hat{a}_i}{p}$ and $\bar{c} = \frac{\Sigma\hat{c}_i}{p}$ where p is the number of experiments in the study.

The unweighted means shown for the two designs (Table 3) were obtained separately. The ratio of the line to the error components of variance in the two designs did not differ widely. Therefore the unweighted mean .583 of the $\hat{c}_i$ in the 11 experiments was used as an estimate of the average ratio of the line and error components of variance.

Since there were only three split-plot designs and since the estimates of $\sigma^2_{LTi}/\sigma^2_{Ei}$ ($\hat{a}_i$) varied considerably, the 11 estimates of $\sigma^2_{LTi}/\sigma^2_{Ei}$ were averaged to give .229 as the average ratio of the line$\times$tester to the error component of variance. If the average values for $\hat{a}_i$ and $\hat{c}_i$ for the randomized blocks designs were used to compute one table and the average values for $\hat{a}_i$ and $\hat{c}_i$ from the split-plot designs were used to compute another table, both tables would deviate little from the one (Table 4) computed by using the rounded averages, $\bar{a}=.23$ and $\bar{c}=.58$, of the 11 experiments.

These results, $\bar{a}=.23$ and $\bar{c}=.58$, may be used in two ways. The first is to predict the number of testers required for a given degree of precision and for a given number of replicates and the second method of using the estimates, $\bar{a}$ and $\bar{c}$, is to predict the average gain in combining ability to be expected from tests utilizing various combinations of lines, replicates, and testers. This will be discussed in a later section. For the first method one might consider a case in which the expected mean yield of an experiment is 30 pounds per plot and the coefficient of variability is 7.5%. The standard deviation squared $=(.075\times30)^2 = 5.06 = s^2_E$ and therefore $s^2_{LT} = \bar{a}s^2_E = .23(5.06) = 1.16$. Assume that the experimenter desires a standard error of a line to be about 3% of the mean. For four replicates, the number of testers required can be determined as follows: $(.03)\ 30 = .9 = \sqrt{\frac{5.06+4(1.16)}{4t}}$. Solving, $t = \frac{9.70}{4(.9)^2} = 3$ testers. Similarly for six replicates then, two testers are required for a standard error which is about 3% of the mean, 30.

TABLE 4.—*A comparison of positive weighted standard deviation units for varying numbers of lines, testers, and replicates when the highest combining inbred line is selected in contrast to a randomly selected line from the same population.*

No. of lines	Average value of largest deviate ($\bar{x}_l$)	Positive standard deviation units with the number of testers indicated					
		1	2	3	4	5	6
		1 Replicate					
25	1.97	0.853	1.050	1.152	1.217	1.263	1.294
50	2.25	0.974	1.199	1.316	1.390	1.442	1.478
75	2.40	1.039	1.279	1.404	1.483	1.538	1.577
100	2.51	1.087	1.338	1.468	1.551	1.609	1.649
150	2.65	1.147	1.412	1.550	1.638	1.699	1.741
200	2.75	1.191	1.466	1.609	1.700	1.763	1.807
300	2.90	1.256	1.546	1.696	1.792	1.859	1.905
500	3.05	1.321	1.626	1.784	1.885	1.955	2.004
		3 Replicates					
25	1.97	1.074	1.235	1.308	1.349	1.377	1.395
50	2.25	1.226	1.411	1.494	1.541	1.573	1.593
75	2.40	1.308	1.505	1.594	1.644	1.678	1.699
100	2.51	1.368	1.574	1.667	1.719	1.754	1.777
150	2.65	1.444	1.662	1.760	1.815	1.852	1.876
200	2.75	1.499	1.724	1.826	1.884	1.922	1.947
300	2.90	1.581	1.818	1.926	1.986	2.027	2.053
500	3.05	1.662	1.912	2.025	2.089	2.132	2.159
		6 Replicates					
25	1.97	1.160	1.300	1.359	1.391	1.411	1.424
50	2.25	1.325	1.485	1.552	1.588	1.611	1.627
75	2.40	1.414	1.584	1.656	1.694	1.718	1.735
100	2.51	1.478	1.657	1.732	1.772	1.797	1.815
150	2.65	1.561	1.749	1.828	1.871	1.897	1.916
200	2.75	1.620	1.815	1.898	1.942	1.969	1.988
300	2.90	1.708	1.914	2.001	2.047	2.076	2.097
500	3.05	1.796	2.013	2.104	2.153	2.184	2.205

The second method of using $\bar{a}$ and $\bar{c}$ is to predict the combining ability of the best inbred line as determined from top-cross tests. Yates (12) and Perotti (8) have given formulas for the average gain in combining ability due to the selection of the apparently best line instead of a randomly selected line from a samples of l lines. These formulas are based on the assumption that the data are normally distributed. Perotti (8) has computed tables illustrating the effect of non-normality on this average gain.

In the notation of this paper the average gain in combining ability due to the selection of the apparently best instead of a random line from a sample of l lines is (vi)[4] $\frac{\sigma^2_L}{\sqrt{\sigma^2_L+\frac{\sigma^2_E}{r}}}\,\bar{x}_l$ where $\bar{x}_l$ is the average combining value, in repeated samples of the highest yielding member of a sample of size l. The value for $\bar{x}_l$ may be found in various

[4]Yates did not include the square root sign in the denominator.

places (6, 9, 11). It is greater than the mean by one half the expected range. Fisher and Yates (6) give the average or mean value for the n^{th}, $n\text{-}1^{st}$, $n\text{-}2^{nd}$, etc., largest members from a sample of size n in terms of positive unit standard deviations. Formula (vi) is applicable to a randomized block experiment involving lines and replicates only. When testers also are involved formula (vi) of Yates (12) and Perotti (8) has been extended to (vii) $\sqrt{\dfrac{\sigma^2_L}{\sigma^2_L+\dfrac{\sigma^2_E}{rt}+\dfrac{\sigma^2_{LT}}{t}}}\ \bar{x}_1$ where $\bar{x}_1=\bar{x}_n$ in Yates (12) notation.

If there were perfect correlation between genotype and phenotype and if the combining ability of a group of lines could be determined with absolute accuracy, then the values for $\bar{x}_1$ could be used directly to compare the relative efficiency of populations of varying size. Unfortunately such an idealized condition is never realized. The error, line, and line$\times$tester variance components are disturbing factors and must be allowed for in any comparison made. Formula (vii) serves as a method of weighting the positive unit standard deviation values of $\bar{x}_1$ on the basis of the observed variance components, (Table 3) i.e., by the standard deviation times the correlation of phenotype and genotype.

Table 4 was constructed by substituting the estimates $\sigma^2_E=1$, $\sigma^2_{LT}=.23$, and $\sigma^2_L=.58$ in formula (vii). To illustrate, in a population of 25 lines, on the average, the highest yielding member will exceed the mean by 1.97 unit standard deviations. When this value is weighted by the estimates of the variance components of σ^2_E, σ^2_L and σ^2_{LT}, we find that if only one replication and one tester are used, the highest yielding item will exceed the mean, on the average, by only .853 weighted standard deviation units. The other values presented were obtained in a similar manner.

When each variable is considered separately, the other two being held constant, it will be noted that the greatest gain in combining value, as judged by the expected combining ability of the highest combining inbred line, is expected with an increase in the number of lines tested. The second greatest gain, similarly measured, is obtained with an increase in the number of testers, and an increase in the number of replicates has the least effect. However, if the number of plots to be grown is held constant, thus avoiding variation in the cost of testing, the greatest gain in combining value is expected with an increase in the number of testers even at the expense of the number of lines tested. For example, it might be assumed that the experimenter wishes to conduct a top cross test involving 100 entries in 3 replicates. From Table 4, greater progress on the average would be made by using 50 lines and 2 testers rather than 100 lines and 1 tester.

The average gain in combining value due to selecting a fixed number of the inbred parents of the highest yielding top-crosses may be predicted in a similar manner. Fisher and Yates (6) have presented tables for the average value of the n^{th}, $n\text{-}1t^{t}$, etc., largest members of a sample of size n. The average of the expected values of a group of the highest combining lines may be used for $\bar{x}_1$ in formula (vii),

and thus obtain the average gain to be expected from selecting such a group in contrast to a random set of lines from the same sample. Unfortunately the maximum n for which tables are available is 50.

DISCUSSION AND CONCLUSIONS

The formula (vi) proposed by Yates (12) and Perotti (8) and the extended formula (vii) presented here deal with average gain in total combining ability as judged by the expected total combining ability of the highest combining member of the sample. Methods for separating total combining ability into two components, general and specific, have been presented by Sprague and Tatum (10). The lines used in this series of 11 experiments had undergone no previous selection for combining ability. The testers used included both single and double crosses. The component of variance s^2_L may be considered as a measure of general combining ability and the component s^2_{LT} as a measure of specific combining ability. The data presented here are in general agreement with the findings of Sprague and Tatum (10) that general combining ability is numerically the greater in previously untested material. Estimates are not available from which one can predict the relative size of the s^2_L and s^2_{LT} components when inbred lines are used as testers. The limited data, however, suggest the ratio of σ^2_L/σ^2_{LT} decreases materially under such conditions.

This indicates that the choice of a suitable tester for a given set of new lines depends on the uses to be made of these lines in a breeding program. If they are considered as potential replacements for a given line in a particular double cross then the tester should be chosen to reveal the maximum specific combining ability. In such a case the approximate tester would be the opposing single cross and the greatest efficiency would be attained with a single tester.

The data presented in Table 4 apply to the more general case in which maximum total combining ability is the desired goal. The greatest gain in total combining ability is expected when more than one tester is used and specific combining ability is, in part at least, averaged out. This insures a high level of general combining ability and leaves selection for specific combining ability to the latter and more precise tests of single crosses.

It should be emphasized that this study of variance components has not led to any new conclusions. However, it does provide some factual basis for opinions which have been held by many corn breeders for a number of years.

SUMMARY

Formulas are presented which permit the estimation of variance components and their ratios in randomized blocks and split-plot designs involving replicates, lines, and testers.

The magnitude of these components have been estimated in 11 experiments. These estimates indicate that for a fixed number of plots the greatest gain in total combining ability can be expected from an increase in number of testers, followed in order by an increase in lines with an increase in number of replicates being least efficient.

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A Summary of Linkage Studies in Barley: Supplement I, 1940-1946[1]

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SINCE the publication of a summary of linkage studies in barley (17)[3] in 1941, several additional factor pairs have been studied by various workers and several additions have been made to our knowledge of linkage relations in barley chromosomes.

The present paper presents a summary of linkage studies from 1940 to 1946. The data will be presented in the same form as in a previous publication by Robertson, Wiebe, and Immer (17).

In the allotment of symbols the same plan has been followed as was used in the previous publication (17). The same general plan has also been used in presenting the data. However, one more table has been added giving the character and symbols allotted where the studies have not been completed and published.

Some slight change has been made in the method of presenting symbols. In the case of multiple factors the first factor pair is given without a number, i. e., green vs. light green seedlings, Lg lg. The second factor pair is given the number 2, Lg2 lg2 any additional factor pairs are numbered in succession. The use of subscripts has been dropped where possible in order to facilitate printing.

GENETIC FACTORS

A list of characters studied by the various workers in barley genetics is presented in Table 1. Recommended symbols are given for each character, as well as the previous symbols used when differing from the recommended symbol and the author describing the character. The symbols are listed alphabetically to facilitate the allotting of new symbols to additional characters.

NEW SYMBOLS ALLOTTED

In Table 2 is presented a list of characters being studied by various workers which have been allotted symbols. The studies are either in progress or have been completed and are not published.

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[1]Contribution from the Department of Agronomy, Colorado Agricultural Experiment Station, Fort Collins, Colo.; the Division of Cereal Crops and Diseases, the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture; and the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis., co-operating. Received for publication December 28, 1946.

[2]Chief Agronomist, Colorado Agricultural Experiment Station; Principal Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture; and Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, respectively. Published with the approval of the Directors as Scientific Journal Series paper 229 of the Colorado Agricultural Experiment Station and Journal Series paper 222 of the Department of Agronomy, Wisconsin Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 472.

LINKAGE GROUPS

The linked genes are placed in seven linkage groups corresponding

TABLE 1.—*Genetic factors studied by workers in barley between 1940 and 1946.*

Character	Symbol recommended	Previous symbol used	Authority*
Normal vs. brittle rachis	Bt bt		8, 17
Normal vs. brittle rachis	Bt 2 bt 2	Bt 1 bt 1	8, 17
Black vs. medium black lemma and caryopsis	B B^{mb}		26
Black vs. gray lemma and caryopsis	B B^{g}		25
Black vs. white lemma and caryopsis	B b	Bk bk	25, 17
Complementary factors for blue vs. non-blue aleurone	Bl bl Bl 2 bl 2	 Bl 1 bl 1	14, 17
Long vs. fine awned glume	E2 e2		6
Green vs. chlorina seedlings	F3 f3		7
Normal vs. grandpa	Gp gp		7
Non glaucous vs. glaucous sheath	Gs gs		7
Normal vs. glossy seedling	Gl gl		7, 17
Hairy vs. pubescent glume†	Gh gh		6
Tall vs. short (modifying factor)	H I h I		23
Resistance vs. susceptibility to *Helminthosporium gramineum*	Hg hg		2
Resistance vs. susceptibility to *H. gramineum*	Hg 2 hg 2		2
Resistance vs. susceptibility to *H. gramineum*	Hg 3 hg 3		2
Pubescent vs. non pubescent rachis	Hr hr	Pbr pbr	6
Pubescent vs. non pubescent rachis	Hr 2 hr 2	Pbr_1 pbr_1	6
Pubescent vs. non pubescent rachis	Hr 3 hr 3	Pbr_2 pbr_2	6
Fertile intermedium vs. non intermedium	I^{h} i		11, 17
Kernel weight multiple factors	Kw kw		9
Green vs. light green seedlings	Lg lg	lg 8‡	7, 17
Green vs. light green seedlings	Lg4 lg4	lg 9 Lg I lg I	7
Green vs. light green seedlings	Lg2 lg2	lg 3	7
Green vs. light green seedlings	Lg3 lg3	lg 7	7
Series of factors for awn length	Lk lk Lk 2 lk 2	 Ss	 15, 17
Normal vs. reduced lateral spikelet appendage on the lemma	Lr lr		10, 17
Resistance vs. susceptibility to mildew race 3	Ml_p ml_p	Ml_x ml_x	22
Resistance vs. susceptibility to mildew race 3	Ml_y ml_y		22
Resistance vs. susceptibility to mildew race 3	Ml_d ml_d		22
Normal vs. multiploid sporocytes	Mu mu		21
White vs. orange lemma	O o		7, 14, 17
Long vs. short rachilla	Ra ra		3
Long vs. short rachilla	Ra 2 ra 2		3
Long vs. short rachilla	Ra 3 ra 3		3
Red stem vs. green stem	Rs rs		4
Normal vs. triple awned lemma	Tr tr		7
Resistance vs. susceptibility to *Ustilago nuda*	Un un		12
Resistance vs. susceptibility to *U. nuda* (minor factor)	Un 2 un 2		12
Allels for deficiens	V^{t} V^{d} v		27
Weakly attached vs. firmly attached spikelet	Ws ws		24
Green vs. virescent seedlings	Y y		17
Green vs. yellow seedlings	Y y^{x}		18
Green vs. zoned leaf	Z z	Zd zd	7

*Figures refer to literature citations.
†The simplified form "glume" will be used in this publication in place of the older term, "outer glume," as suggested by Aberg and Wiebe (1).
‡Original Missouri numbers.

to the seven chromosomes. Linkage groups have been established on the independent inheritance of genes in different chromosomes. The linkage and associations reported in the literature are listed in Table 3.

FACTORS SHOWING INDEPENDENT INHERITANCE

The factors showing independent inheritance are listed in Table 4, according to the various linkage groups. For instance, if a factor pair in group II is found to be independent of (Vv) non-six row vs. six-row in group I, then non-six-rowed vs. six-rowed will not be listed as being independent of this factor pair when the factor pair is listed in relationship to other independently inherited characters. Thus, when a character is listed as independent of another character, this relationship will not be shown again.

TABLE 2.—*Symbols allotted to characters in unpublished studies from 1940 to 1946.*

Character	Symbol
Hairy leaf sheath	Hs hs
Resistance vs. susceptibility to *Puccinia anomala*	Pa pa
Resistance vs. susceptibility to *P. anomala*	Pa2 pa2
Rattail spike	Rt rt
Resistance vs. susceptibility to *Fusarium* scab	Sc sc
Resistance vs. susceptibility to *U. Hordei*	Uh uh
Second male sterile factor	Ms 2 ms 2
Normal vs. waxy endosperm	Wx wx
Normal vs. tweaky	Tw tw
Normal vs. streaked (ribbon grass)	Rb rb
Glaucous vs. non glaucous head	Ge ge
Normal vs. long chromosome	Lc lc

POLYSOMICS AND POLYPLOIDS

A few barley strains have been found or produced in which the chromosome number is greater or smaller than the normal diploid number of 14. The various types reported are listed in Table 5.

TABLE 3.—*Linkage and association reported in studies of barley genetics from 1940 to 1946.*

Character	Recommended symbol	Previous symbol	Percentage recombination	Authority*
Group I				
Non-six-rowed vs. six-rowed (Vv) in relation to:				
Normal vs. long awned glume. .	E e		26.6±0.6	19
Normal vs. long awned glume. .	E e		28.0±1.2	7
Normal vs. long awned glume. .	E e		26.7±1.7	23
Tall vs. short.	H h		25.4±1.6	23
Green vs. light green seedling. . .	Lg lg	lg 8	31.0±2.5	7
Awned vs. awnless.	Lk lk		0.0	19
Awned vs. awnless.	Lk lk		9.6	17
Normal vs. reduced lateral spikelet appendage on the lemma.	Lr lr		0.0	10
Purple vs. white pericarp.	P p		13.9±2.17	14
Rachis internode number.	Rin rin		17.1±1.3	23
Normal vs. triple awned lemma	Tr tr		39.0±3.0	7
Green vs. yellow seedlings.	Y y^x		31.0	18
Awned vs. awnless (Lk lk) in relation to:				
Green vs. chlorina seedlings. . . .	F f		28.4±0.8	19
Green vs. virescent seedlings. . .	Y y		26.9±1.4	19
Normal vs. long awned glume (E e) in relation to:				
Green vs. chlorina seedlings. . . .	F f		2.6±0.8	19
Tall vs. short.	H h		8.1±0.9	23
Normal vs. light green seedlings	Lg lg	lg8	4.0±1.2	7
Green vs. orange seedling.	Or or		14.8±0.9	19
Rachis internode number.	Rin rin		15.1±1.2	23
Normal vs. triple awned lemma	Tr tr		41.0±2.9	7
Tall vs. short (H h) in relation to:				
Rachis internode number.	Rin rin		12.8±1.1	23
Normal vs. triple awned lemma (Tr tr) in relation to:				
Normal vs. light green seedlings	Lg lg	lg8	52.0±9.0†	7
Green vs. virescent seedlings (Y y) in relation to:				
Normal vs. light green seedlings	Lg lg	lg8	2.0±0.5	7
Green vs. yellow seedling (Y y^x) in relation to:				
Green vs. chlorina seedlings. . . .	F f		1.7	18
Green vs. orange seedlings.	Or or		15.0	18
Normal vs. reduced lateral spikelet appendage on the lemma lemma (Lr lr) in relation to:				
Green vs. orange seedling.	Or or		38.58±1.20	10
Group II				
Allelomorphic series of factors for melanin like pigment in the glumes and caryopsis of barley B, B^{mb}, B^g, b in relation to:				
Green vs. white seedlings.	A_t a_t		36.7	26
Green vs. white seedlings.	A_t a_t		22.3	17

TABLE 3.—*Continued.*

Character	Recommended symbol	Previous symbol	Percentage recombination	Authority*
Green vs. white seedlings (A_t a_t) in relation to:				
Resistance vs. susceptibility to Mildew race 3	Ml_p ml_p		36.65	4
Susceptibility vs. resistance to Mildew race 3	Ml_d ml_d		12.08	4
Resistance vs. susceptibility to mildew race 3(Ml_p ml_p) in relation to:				
Susceptible vs. resistance to mildew race 3	Ml_d ml_d		16.38	4
	Group III			
Covered vs. naked caryopsis (Nn) in relation to:				
Complementary factor for the blue aleurone	Bl 2 bl 2		9.88±0.44	14
Red stem vs. green stem	Rs rs		14.5±1.06	4
Complementary factor pair for blue aleurone (Bl 2 bl 2) in relation to:				
Red stem vs. green stem	Rs rs		9.07±1.24	4
	Group IV			
Hooded vs. awned (Kk) in relation to:				
Blue vs. non-blue aleurone	Bl bl		44.0±6.3	7
Blue vs. non-blue aleurone	Bl bl		24.72±1.73	14
Blue vs. non-blue aleurone	Bl bl		40.6	17
Blue vs. non-blue aleurone	Bl bl		22.0	17
Normal vs. glossy seedling	Gl gl		10.0±0.8	7
Normal vs. glossy seedling	Gl 2 gl 2		15.1	18
Infertile intermedium vs. fertile intermedium	I^h i		14.3±0.6	11
Normal vs. light green seedlings	Lg 4 lg 4	Lg 1 lg 1 lg 9	5.0±1.0	7
Normal vs. light green seedlings	Lg 2 lg 2	lg 3	2.0±1.4	7
Resistance vs. susceptibility to mildew race 3	Ml_g ml_g		18.8±2.3	4
Normal vs. zoned leaf	Z z	Zd zd	6.0±0.8	7
Infertile intermedium vs. non-intermedium (Ii) in relation to:				
Normal vs. glossy seedlings	Gl 2 gl 2		28.0	18
Normal vs. zoned leaf (Z z) in relation to:				
Normal vs. glossy seedling	Gl gl		3.0±0.5	7
Normal vs. light green seedlings	Lg4 lg4	Lg 1 lg 1 lg 9	1.0±0.4	7
Normal vs. light green seedling (Lg4 lg4) in relation to:				
Normal vs. glossy seedling	Gl gl		4.0±0.6	7
Normal vs. glossy seedling (Gl gl) in relation to:				
Blue vs. non-blue aleurone	Bl bl		36.0±3.3	7
Blue vs. non-blue aleurone (Bl bl) in relation to:				
Resistance vs. susceptibility to mildew race 3	Ml_g ml_g		26.3±5.0	4

TABLE 3.—*Concluded.*

Character	Recommended symbol	Previous symbol	Percentage recombination	Authority*
Group V				
Long vs. short haired rachilla (S s) in relation to:				
Long vs. short rachilla.	Ra ra		Apparent	3
Rough vs. smooth awn (R r) in relation to:				
Spring habit of growth.	Sh sh		Correlated	13
Group VII				
Green vs. virescent seedlings (Y_c y_c) in relation to:				
Green vs. chlorina seedlings. . . .	F_c f_c		33.0±1.7	7
Green vs. chlorina seedlings. . . .	F_c f_c		29.3	17
Normal vs. brachytic.	Br br		34.0±1.8	7
Resistance vs. susceptibility to *P. graminis tritici*.	Tt		60.0±3.4‡	7
Resistance vs. susceptibility to loose smut (Un un) in relation to:				
Resistance vs. susceptibility to *P. graminis tritici*.	Tt		Apparent	20
Resistance vs. susceptibility to *P. graminis tritici* in relation to:				
Kernel weight (multiple factor)	Kw kw		Correlated	9
Miscellaneous				
Long vs. short awn (Lk lk) in relation to:				
Breaking strength of straw.	Sts sts		Correlated	6
Length of rachis internode (L_x l_x) in relation to:				
Long vs. short awn on the glume	E2 e2		34.0±1.29	6
Long vs. short awn on the glume (E2 e2) in relation to:				
Pubescent vs. glabrous rachis. .	Hr hr	Pbr_1 pbr_1	17.2±28.0	6

†Shows independence but is located in chromosome I.
‡Shows independence but is located in chromosome VII.
*Figures refer to literature citations.

TABLE 4.—*Factor pairs showing independent inheritance as reported by workers on barley genetics from 1940 to 1946.*

Linking group	Recommended symbol	Previous symbol	Authority*
Non-six-rowed vs. six-rowed (Vv) independent of:			
Green vs. chlorina seedling	F3 f3		7
Normal vs. grandpa	Gp gp		7
Normal vs. light green seedlings	Lg3 lg3	lg7	7
Normal vs. glaucous sheath	Gs gs		7
Resistance vs. susceptibility to *U. nuda*	Un un		12
Resistance vs. susceptibility to mildew race 3	Mlp mlp		5
White vs. orange lemma	O o		14
Resistance vs. susceptibility to *H. gramineum*	Hg hg		2
Resistance vs. susceptibility to *H. gramineum*	Hg 2 hg 2		2
Resistance vs. susceptibility to *H. gramineum*	Hg 3 hg 3		2
Fertile intermedium vs. non-intermedium	I^h i		11
Normal vs. glossy seedlings	Gl 2 gl 2		18
Green vs. chlorina seedlings (F f) independent of:			
Normal vs. glossy seedlings	Gl 2 gl 2		18
Black vs. white glume and caryopsis (B b) independent of:			
Awned vs. awnless lemma	Lk lk		19
Normal vs. long awned glume	E e		19
Green vs. chlorina seedlings	F3 f3		7
Normal vs. grandpa	Gp gp		7
Normal vs. light green seedlings	Lg3 lg3	lg7	7
Normal vs. glaucous sheath	Gs gs		7
Normal vs. brittle rachis	Bt I bt I		8
Fertile intermedium vs. non-intermedium	I^h i		11
Green vs. yellow seedlings	Yy^x		18
Normal vs. glossy seedlings	Gl 2 gl 2		18
Resistance vs. susceptibility to *H. gramineum*	Hg hg		2
Resistance vs. susceptibility to *H. gramineum*	Hg 2 hg 2		2
Resistance vs. susceptibility to *H. gramineum*	Hg 3 hg 3		2
Green vs. white seedlings (A_t a_t) independent of:			
Normal vs. glossy seedlings	Gl 2 gl 2		18
Awned vs. awnless lemma	Lk lk		19
Covered vs. naked caryopsis (Mn) independent of:			
Green vs. chlorina seedlings	F3 f3		7
Normal vs. light green seedlings	Lg 3 lg 3	lg 7	7
Normal vs. glaucous sheath	Gs gs		7
Normal vs. long awned glume	E e		19
Purple vs. non purple lemma	P p		14
Fertile intermedium vs. non-intermedium	I^h i		11
Awned vs. awnless lemma	Lk lk		19
Green vs. yellow seedlings	Yy^x		18
Normal vs. glossy seedlings	Gl 2 gl 2		18
White vs. orange lemma	O o		14
Resistance vs. susceptibility to mildew race 3	Ml_p ml_p		5
Resistance vs. susceptibility to *H. gramineum*	Hg hg		2
Resistance vs. susceptibility to *H. gramineum*	Hg 2 hg 2		2
Resistance vs. susceptibility to *H. gramineum*	Hg 3 hg 3		2
Green vs. white seedling ($A_{c2}a_{c2}$) independent of:			
Green vs. glossy seedlings	Gl 2 gl 2		18
Awned vs. awnless lemma	Lk lk		19
Complementary factor for blue aleurone (Bl I bl I) independent of:			
White vs. orange lemma	O o		9
Hooded vs. awned (K k) independent of:			
Normal vs. grandpa	Gp gp		7

TABLE 4.—*Continued.*

Linking group	Recommended symbol	Previous symbol	Authority*
Green vs. chlorina seedlings	F3 f3		7
Green vs. light green seedlings	Lg3 lg3	lg 7	7
Normal vs. glaucous sheath	Gs gs		7
Normal vs. long awned glume	E e		19
Awned vs. awnless lemma	Lk lk		19
Green vs. yellow seedlings	Yy^x		18
White vs. orange lemma	O o		14
Resistance vs. susceptibility to *U. nuda*	Un un		12
Resistance vs. susceptibility to mildew race 3	$Ml_p\ ml_p$		5
Normal vs. light green seedlings (Lg4 lg4) independent of:			
Normal vs. grandpa	Gp gp		7
Rough vs. smooth awn (Rr) independent of:			
Normal vs. grandpa	Gp gp		7
Green vs. chlorina seedlings	F3 f3		7
Normal vs. light green seedlings	Lg 3 lg 3	lg 7	7
Green vs. yellow seedlings	Yy^x		17
Normal vs. long awned glume	E e		19
Awned vs. awnless lemma	Lk lk		19
Purple vs. non purple lemma	P p		12
White vs. orange lemma	O o		14
Resistance vs. susceptibility to *H. gramineum*	Hg hg		2
Resistance vs. susceptibility to *H. gramineum*	Hg 2 hg 2		2
Resistance vs. susceptibility to *H. gramineum*	Hg 3 hg 3		2
Long vs. short haired rachilla (Ss) independent of:			
Normal vs. grandpa	Gp gp		7
Green vs. chlorina seedling	F3 f3		7
Normal vs. light green seedling	Lg 3 lg 3	lg 7	7
Fertile intermedium vs. non-intermedium	$I^h\ i$		11
Normal vs. yellow seedlings	$Y\ y^x$		18
Normal vs. glossy seedling	Gl 2 gl 2		18
Normal vs. long awned glume	E e		19
Awned vs. awnless lemma	Lk lk		19
White vs. orange lemma	O o		14
Resistance vs. susceptibility to *H. gramineum*	Hg hg		2
Resistance vs. susceptibility to *H. gramineum*	Hg 2 hg 2		2
Resistance vs. susceptibility to *H. gramineum*	Hg 3 hg 3		2
Green vs. Xantha seedlings ($X_c\ x_c$) independent of:			
Green vs. chlorina seedlings	F3 f3		7
Normal vs. light green seedlings	Lg 3 lg 3	lg 7	7
Awned vs. awnless lemma	Lk lk		19
Resistance vs. susceptibility to mildew race 3	$Ml_p\ ml_p$		5
Green vs. white seedlings ($A_n a_n$) independent of:			
Green vs. yellow seedlings	Yy^x		18
Green vs. glossy seedlings	Gl 2 gl 2		18
Normal vs. long awned glume	E e		19
Awned vs. awnless lemma	Lk lk		19
Green vs. Xantha seedlings ($X_s\ x_s$) independent of:			
Non-fertile vs. fertile intermedium	$I^h\ i$		11
Green vs. chlorina seedlings ($F_c\ f_c$) independent of:			
Normal vs. grandpa	Gp gp		7
Green vs. chlorina seedlings	F3 f3		7
Green vs. yellow seedlings	Yy^x		18
Green vs. glossy seedlings	Gl 2 gl 2		18
Awned vs. awnless lemma	Lk lk		19
Normal vs. brachytic (Br br) independent of:			
Normal vs. grandpa	Gp gp		7

TABLE 4.—*Concluded.*

Linking group	Recommended symbol	Previous symbol	Authority*
Normal vs. chlorina seedlings	F3 f3		7
Normal vs. light green seedlings	Lg 3 lg 3	lg 7	7
Resistance vs. susceptibility to *H. gramineum*	Hg hg		2
Resistance vs. susceptibility to *H. gramenium*	Hg 2 hg 2		2
Resistance vs. susceptibility to *H. gramineum*	Hg 3 hg 3		2
Resistance vs. susceptibility to mildew race 3	Ml_p ml_p		5
Green vs. virescent seedlings (Y_cy_c) independent of:			
Green vs. yellow seedlings	Y y^x		18
Green vs. glossy seedlings	Gl 2 gl 2		18
Awned vs. awnless lemma	Lk lk		19
White vs. orange lemma (O o) independent of:			
Green vs. chlorina seedlings	F3 f3		7
Purple vs. non-purple lemma	P p		14

*Figures refer to literature citations.

TABLE 5.—*Polysomics and polyploids listed by workers on barley genetics.*

Type	Variety	How produced	Authority*
Multiploid sporocytes	Contabescent anther C. I. 3845	Spontaneous	21
Haploid	Species cross	Hybrid	16

*Figures refer to literature citations.

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The I^h, I, i Allels in *Hordeum deficiens* Genotypes of Barley[1]

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THIS paper presents the results of a study of the I^h, I, i factors in *Hordeum deficiens*. These factors are known to affect the degree of development of the lateral florets in *Hordeum intermedium* as well as in certain heterozygotes. They are located in linkage group 4, while the V, V^t v allels are in group I. A vv genotype is known as six-rowed, regardless of the presence of I^h, I, i allels. Varieties of *H. distichon* have been assigned a VVii genotype, while *H. intermedium* strains are either VVII or VVI^hI^h. Several recent investigations indicate that additional genotypes may exist in each of the barley species. Complicated ratios, such as were indicated by Gillis,[3] for crosses between the four barley species have not appeared in these studies. The present paper presents the results of a study of the fertility factors (I^h, I, i) in five varieties of deficiens, and the inheritance of the deficiens character.

MATERIALS AND METHOD

Nearly 100 varieties and strains of *H. deficiens* were available as parental material in this study. Most of these contained either melaninlike or anthocyanin pigments since they were collected for a color inheritance study. Five strains showing color variations as well as a degree of difference for their vestigial lateral florets were selected and crossed to Svanhals, a strong two-rowed type with well-developed unfertile lateral florets. Typical spikes of each of the species used in these studies are shown in Fig. 1. The five strains of *H. deficiens* used in crosses were White deficiens (C. I. 7316)[4], Black deficiens (B1–C1)[5] (C. I. 7317), C. I. 3949, C. I. 3951–2, and C. I. 7140[6].

White deficiens is unpigmented, has a lax spike, and only a slight vestige of lemma and occasionally palea in the lateral florets. The central florets are fully fertile, a condition found in all barley species.

C. I. 3949 has black pigment in the glumes and pericarp, while the lateral florets are slightly more pronounced than in White deficiens.

C. I. 3951–2 and *C. I. 7140* are similar in most respects, except that *C. I. 3951–2* has a much more dense pattern of purple color in the spike, upper culm, and leaves. Both have but slight vestiges of lateral florets, being much the same as White deficiens in this respect.

Black deficiens (B1–C1) has, as the name implies, dense black pigment in both the glumes and the naked caryopsis. The development of rudimentary floral structures in the lateral florets exceeds that of any other deficiens variety used in this study. They are not nearly so pronounced, however, as those found in *H. deficiens nudideficiens* described by Leonard[7], as a VVii or two-rowed variety.

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[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating with the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Received for publication January 31, 1947.

[2]Associate agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering.

[3]GILLIS, M. C. A genetical study of the fertility of the lateral florets in barley spikes. Jour. Agr. Res., 32:367–390. 1926.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

[5]Obtained from the Department of Agronomy and Plant Genetics, University of Minnesota.

[6]Obtained from H. V. Harlan of the U. S. Dept. of Agriculture.

[7]LEONARD, WARREN H. Inheritance of fertility in the lateral spikelets of barley. Ph.D. thesis presented to the University of Minnesota, St. Paul, Minn. 1940.

Several families, including those from reciprocal crosses, were analyzed in each cross in the F_2 generation and a few families were studied in the F_3. In all, several thousand F_2 plants were classified. Special attention was given to deter-

Fig. 1.—Typical heads of Svanhals (A), a two-rowed barley, and varieties of deficiens (B) with their F_1 or heterozygous type (C) found when five varieties of *Hordeum deficiens* were crossed to Svanhals.

mine if any of the factors studied were linked with the Vv loci. A few crosses involving the factors V^t, V, and v are included to show evidence of their allelic relationship.

EXPERIMENTAL RESULTS

Six-rowed varieties are usually crossed with *H. distichon* in order to classify them for the presence of I^h, I, i allels. The *distichon* VVii type and intermedium VVII or VVI^hI^h can be used if the gentoype is known, although the VVii type is preferable since the I^h, I, i relationship is expressed readily in the presence of VVii but is masked by the vv of the six-rowed varieties. The I^h, I, i allels are hypostatic to vv. Likewise, the V^tV^t factor for deficiens are epitatic to the I^h, I, i genes if present, as would be reasonable to suspect. If the V^tV^t genes are allelic to vv, then a study similar to that made in six-rowed varieties would reveal the I^h, I, i genotype in deficiens.

Five crosses, each involving a strain known morphologically as *H. deficiens*, were made with a two-rowed VVii type, named Svanhals (Fig. 1). It was assumed that should either the I^h or I factor be present in *H. deficiens*, intermediums as well as two-rowed individuals would appear in the F_2 generation in a definite ratio, but if ii factors were present in the deficiens variety, no intermediums would appear.

Fortunately, in the five crosses reported, three different deficiens genotypes were found, V^tV^tii, V^tV^tII, and $V^tV^tI^hI^h$, corresponding in their I^h, I, i makeup to the three six-rowed genotypes. Since dominance is not complete in any of the fertility classes, all degrees of intermediate classes may be found in the F_2 generation. In these crosses the F_2 could be classified into deficiens (Fig. 1 B), which was homozygous, a weak sort of two-rowed-like type or the heterozygous class (Fig. 1 C), a group of either strong two-rowed or a combination of two-rowed (Fig. 1 A), and intermediums (Fig. 2). The factor for lesser development in the lateral florets tends to be dominant to the factors for greater development or the presence of kernels. After verification by the growing of a few F_3 families in their entirety, it was concluded that both the deficiens and the heterozygous classes could be counted in the F_2 generation with a fair degree of accuracy. This necessitates only a small sample from each class being carried into the F_3 generation. Only those plants having the (VV) genotypes were then carried in their entirety through the F_3 generation.

White deficiens × Svanhals gave only the parental classes in a homozygous condition in the F_2 generation indicating a V^tV^tii genotype for the deficiens parent. Black deficiens (B1–C1) by Svanhals produced infertile intermedium segregates in the F_2 generation characterized by rounded and extended glumes in their lateral florets with occasionally one or two undersize kernels present. Ratios in the F_2 generation as determined by their F_3 behavior were 4:8:3:1 for deficiens, heterozygous, two-rowed, and infertile intermediums, respectively. These data indicate that Black deficiens B1–C1 is of the genotype V^tV^tII.

Crosses of C. I. 3949, C.I. 3951–2, and C.I. 7140, by Svanhals also gave 4:8:3:1 ratios in the F_2 generation. The "intermediums" in these crosses usually produced 2 or more, and often more than 20, lateral kernels per spike, located usually near the center or the upper half of

the spike. These three strains would then be $V^tV^tI^hI^h$ in their genotypic makeup. Results of all crosses reported in this paper are summarized in Table 1 and the probable genotypes of the *H. deficiens* strains are given.

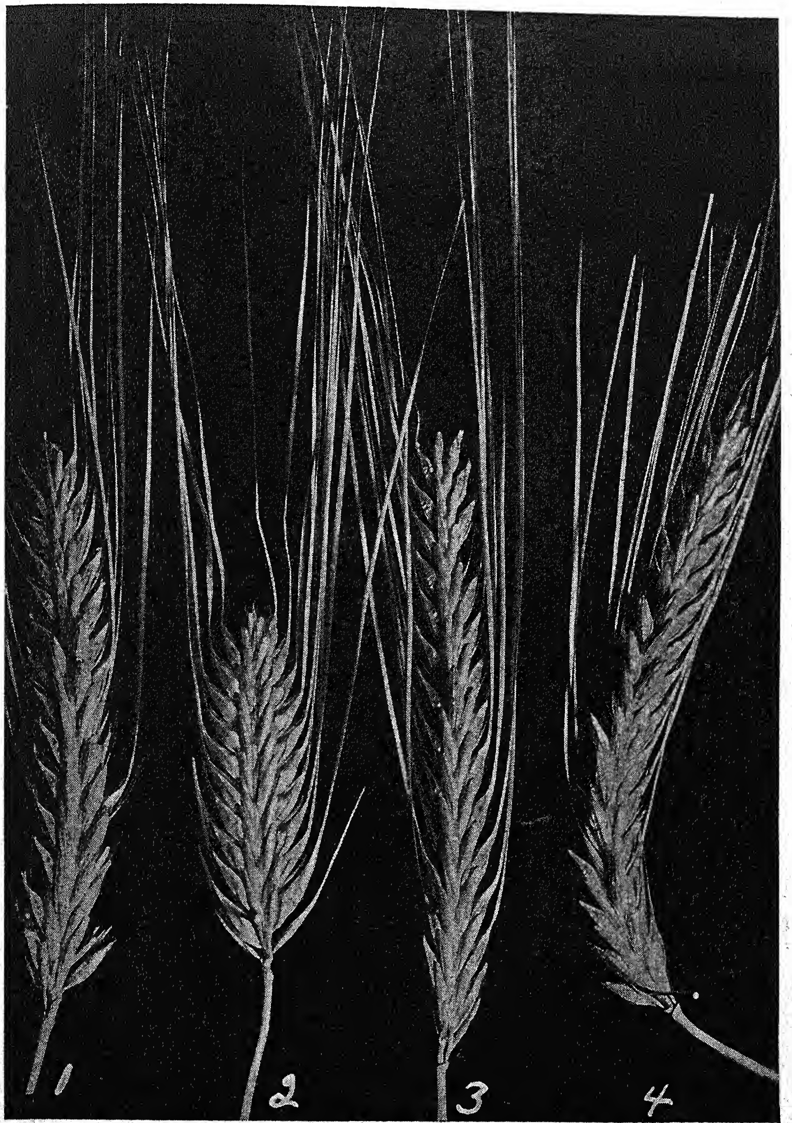

FIG. 2.—Heads of *Hordeum intermedium* showing typical fertile spikes, VVI–I– (1 and 4), and infertile spikes VVII (2 and 3) produced in four crosses of Svanhals by varieties of *Hordeum deficiens* barley.

TABLE 1.—*Segregation of families into F_2 genotypes from crosses between Svanhals VVii and five strains of H. deficiens barley with one family from each cross classified on their breeding behavior in F_3.*

Cross and generation	Deficiens V^tV^t	Heterozygous V^tV	Two-rowed VVii	Segregating two-rowed and intermediums VVIi	Intermediums VVII or VVI^hI^h	Probable genotype of deficiens parent
White deficiens × Svanhals F_2	579	1,092	593	—	—	V^tV^tii
White deficiens × Svanhals F_3	—	—	295	—	—	
Black deficiens (B1–C1) × Svanhals F_2	273	522	249	—	—	V^tV^tII
Black deficiens (B1–C1) × Svanhas F_3	65	107	55	—	16	
Black deficiens (B1–C1) × Svanhals F_3 (VV) plants	—	—	19	36	16	
C. I. 3949 × Svanhals F_2	737	1,349	560	—	244	V^tV^tII and $V^tV^tI^hI^h$ or $V^tV^tI^hI$
C. I. 3949 × Svanhals F_3 (VV) plants	—	—	133	240	129	
C. I. 3951–2 × Svanhals F_2	923	1,676	623	—	208	$V^tV^tI^hI^h$
C. I. 3951–2 × Svanhals F_3 (VV) plants	—	—	104	200	116	
C. I. 7140 × Svanhals F_2	1,231	2,569	1,102	—	320	$V^tV^tI^hI^h$
C. I. 7140 × Svanhals F_3 (VV) plants	—	—	58	145	66	

In offering the suggested genetic constitution for the five strains of *H. deficiens*, it is assumed that these strains are homozygous for their respective I^h, I, i genes as reported here. Their purity for these factors has not been fully determined.

The intermediums from C. I. 3949 × Svanhals were not so fertile as were those from the crosses in which C. I. 3951–2 and C. I. 7140 were used. Spikes from the F_2 intermediums of C. I. 3949 × Svanhals often had several fertile lateral kernels although most spikes showed no kernels. The 573 F_3 rows from this cross indicated a tendency for the intermediums to be mostly of the infertile phenotype having in general no lateral kernels. It is possible that a plant of the $V^tV^tI^hI$ genotype could have been used in the original cross or that female plants might have been of different genotypes and that both fertile and infertile intermediums were thus produced. All the other crosses behaved as would be expected from the assigned genotypes. References in the literature to crosses of *deficiens* × *distichon* in which 1:2:1 ratios prevail might easily have been 4:8:3:1 ratios in certain cases since only careful inspection in the F_2 and a verification in the F_3 generation would reveal the difference between strong two-rowed and infertile intermedium plants. As noted above, considerable variation in fertility of laterals was observed.

Intermediums differ considerably in fertility in response to soil fertility, moisture, spacing, time of seeding, and other factors affecting growth. The degree of fertility varies between different spikes on a single plant, and in the progeny of a single spike known to be homozygous for either high or low fertility as shown in Table 2.

The lateral floret of the two-rowed parent Svanhals used in these studies has a strongly developed lemma and palea (Fig. 1 A), exceeding in some cases those found in infertile intermediums. Many varieties cannot be properly classified until they have been crossed to known genotypes. In general, two-rowed varieties have their lateral florets much more flattened or compressed than do infertile intermediums.

LINKAGES

Purple (Pr) vs. white (pr) color in the glumes and straw was found to be linked to deficiens (V^t) vs. nondeficiens (V^d) in crosses of C. I. 3951–2 and C. I. 7140×Svanhals, with recombinations of 9.3% and 18.9%, respectively (Table 3). This evidence would indicate a high probability that the V^t gene for deficiens is an allel to the v gene since six-rowed vs. no-six-rowed was found by Robertson[8] to be linked with purple vs. white color in barley culms with a recombination value of 9%. Dominance for fertility of the lateral floret in the barley species is incomplete, but the heterozygous group can be combined with the deficiens for coupling or with the nondeficiens for the repulsion phase. A recombination of 12.3% was obtained from the F_3 cross C. I. 3951–2×Svanhals in the repulsion phase and 9.8% in the coupling phase. It was felt that where a choice existed the coupling phase would be preferred for working out crossover percentages in these studies. Since it was easy to separate the fertility groups into a 1:2:1 ratio, this made six classes with purple and white. The re-

[8]ROBERTSON, D. W. Inheritance in barley. Genetics, 18:148–158. 1933.

TABLE 2.—*Number of lateral florets with seeds per spike in parental and progeny spikes of intermedium genotypes VVI^hI^h or $VVII$ from selected crosses.*

Parental spike	Number of lateral florets with seeds per spike in Progeny spikes													Number of progeny plants studied	
	0	1	2	3	4	5	6	7	8	9	10	11	12+	Having lateral florets with seeds	Having no lateral florets with seeds
26	—	—	—	3	—	—	1	1	1	4	2	1	33	8	0
24	—	2	—	1	—	1	1	3	1	2	2	—	3	8	0
24	3	5	4	2	7	6	3	1	4	2	—	10	2	8	0
10	45	26	9	7	12	3	3	2	1	3	1	1	1	13	3
10	11	12	4	9	6	3	3	—	5	4	5	3	1	8	0
8	3	2	3	1	—	—	1	4	—	1	2	3	4	4	0
7	40	8	—	1	1	—	3	1	2	1	1	—	—	5	3
6	49	13	6	4	—	—	—	—	—	—	—	—	—	10	0
5	30	12	8	7	1	5	—	—	—	—	—	—	1	9	0
4	10	5	4	3	4	5	3	4	3	2	1	1	12	8	0
1	46	9	2	1	4	—	2	—	1	1	—	—	1	6	2
1	27	11	3	2	—	—	—	—	1	1	—	1	—	6	2
0	62	10	4	1	1	—	—	—	—	—	—	—	—	7	1
0	43	4	3	1	1	1	—	—	—	—	—	—	—	4	4
0	50	1	1	—	—	—	1	—	—	—	—	—	—	3	5
0	45	1	—	—	—	—	—	—	—	—	—	—	—	1	7
0	74	—	—	—	—	—	—	—	—	—	—	—	—	0	8
0	78	5	1	1	1	1	—	—	—	—	—	—	—	4	10
0	38	—	—	—	—	—	—	—	—	—	—	—	—	0	8
0	44	—	—	—	—	—	—	—	—	—	—	—	—	0	8
0	52	9	6	2	4	2	—	—	1	1	—	—	1	7	1

TABLE 3.—*Phenotypic distribution of F_2 and F_3 populations from barley crosses in which linkage was suspected with percentage recombinations for each cross as shown by maximum likelihood.*

Cross	Purple			White			Percentage recombinations
	Deficiens	Heterozygous	2-row	Deficiens	Heterozygous	2-row	
C. I. 7140 × Svanhals F_2 . . .	572	936	138	83	236	645	18.9 ± 0.20
C. I. 7140 × Svanhals F_3 . . .	108	164	35	0	17	161	9.3 ± 0.71
C. I. 3951–2 × Svanhals F_2 .	877	1,507	139	46	162	685	11.9 ± 0.17
C. I. 3951–2 × Svanhals F_3 .	216	425	41	2	36	162	9.7 ± 0.33
Totals	1,773	3,032	353	131	451	1,653	14.1 ± 0.36

combination values for the six classes by the maximum likelihood formula are shown in Table 3.

SUMMARY AND CONCLUSIONS

The deficiens character (designated V^t) for rudimentary floral structures in the lateral florets behaves as an allel of the V, v factor for the two-rowed vs. six-rowed condition, and is at least partially dominant to them. The V^tV^t genotype is sepitatic to the fertility alleles I, I^h, or i, but when crossed with a V^dV^dii tester stock the genotypes of these latter factors can be determined. Deficiens varieties with I^hI^h, II, and ii genotypes were identified by this means. Considerable variation in lateral floret fertility was noted between differences.

There also was considerable variation in lateral floret fertility from plant to plant within a given strain and between different heads on the same plant.

In several intermediums characterized by having relatively high numbers of lateral kernels, the percentage of lateral kernels was significantly higher in plants grown 6 inches apart in the row than in those seeded at higher rates.

The combined data, F_2 and F_3, from all crosses showed a recombination value of 14.1% $\pm$ 0.36 for the genes V^tV^d and Prpr. For the more accurate F_3 data, when taken alone, this value is 10.1 $\pm$ 1.033.

Soil-Guayule Relationships[1]

JOHN L. RETZER AND CLINTON A. MOGEN[2]

MORE than half of the world's agricultural wealth is derived from products of plants originally obtained from the New World. The cultivation and improvement of these plants begun by the American Indians has been continued for several hundred years. Guayule (y-oo'-lay), *Parthenium argentatum* Gray, is the only crop recently developed from the wild state which may assume prominence in American and world agriculture. Domestication and improvement of the shrub began about 1907, several years following the first milling of the wild shrub in Mexico. Plant improvement work, consisting largely of selection from many strains, was carried on in California, beginning in 1912, and later in Arizona. In 1925–26 operations were centered at Salinas, Calif. An intensive research program was launched in 1942 dealing with all phases of guayule improvement and culture.

The object of this investigation was to study plantation guayule under different soil conditions. Differences were measured by comparing pounds of rubber produced per acre on the several soils. Some 31,000 acres of guayule were distributed over California under different climatic and soil conditions. Smaller plantings were located in Arizona, New Mexico, and Texas.

GUAYULE BELT

NATIVE HABITAT

Guayule is indigenous to the Chihuahuan desert of Northern Mexico and the Big Bend region of Texas (Fig. 2). It grows in scattered patches of from less than one to several hundred acres in size. Plant size and density vary greatly, in part a result of harvesting and grazing practices, but also because of the environmental pattern throughout its range. Typically, guayule is a foot-slope or foothill growth where the very shallow and stony soils are developed from limestone rocks (Fig. 1A, B). It avoids gently sloping lands or valleys where the soils are deep, possibly because of competition with grasses and weeds for the limited moisture. Excess moisture during periods of flood is detrimental. Native guayule is a greenish-gray, spreading, low-growing shrub averaging about 20 inches in height. Weight of 20 pounds per shrub have been reported, but common weights range between 1 and 4 pounds. Lloyd (4)[3] reports that the native shrub has a dual root system, that is, a tap root and a spreading shallow system of fine roots which pick up moisture from desert showers. This shallow root system (Fig. 1 C)[4] is not common for cultivated shrub. The plant is not abundant at altitudes greater than 7,000 feet.

CLIMATE

The northern limits of guayule production in the United States are determined

[1]Contribution from U. S. Forest Service, Emergency Rubber Project, Los Angeles, Calif. Received for publication December 9, 1946.

[2]Soil Scientists, Division of Soil Survey, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture.

[3]Figures in parenthesis refer to "Literature Cited", p. 512.

[4]Figs. 1C, 4 A and B; and 5A and B were drawn in connection with studies made in 1943–44 by C. H. Muller and are used in this report through his courtesy and permission.

by temperature. In the Big Bend region temperatures approach 0°F about one-fourth of the years of record. This may not be taken too literally because of air drainage and possible thermal belts in the rough terrain (Fig. 1 A). Frost damage occurred on cultivated guayule in some localities when temperatures dropped to between 20° and 28°F. In other places plants were killed by 5°F temperatures, while similar temperatures only damaged the shrub in still other localities. Cold injury seems to depend on the physiological condition of the plant at the time of freezing. Based upon present knowledge of temperature tolerance and in part on major relief features, the boundaries of the guayule belt have been drawn as shown in Fig. 2, where the safe, hazardous, and unsafe zones are roughly delineated. The hazardous zone considers low temperatures as well as the frequency of their occurrence. Damaging frosts occur within the safe zone at infrequent intervals.

Rainfall is insufficient to produce a fair-sized guayule plant short of 10 to 15 years in the native habitat. Under irrigation this size is attained or exceeded in 1 to 2 years. The western part of the guayule belt is arid or semi-arid with irrigation required for most crops. The belt is terminated on the east side by precipitation at present considered excessive for successful rubber production. This is in part due to the amount and more or less uniform seasonal distribution of rainfall which promotes luxuriant growth, but provides no rest or dormant period for rubber deposition within the plant, and to such other unfavorable factors as the prevalence of diseases and excessively moist soil conditions which favor root rots.

EXPERIMENTAL PROCEDURE

One, two, and three-year-old (growing seasons) plantation guayule was studied to obtain a comparative measure between different soil conditions and the size and rubber content of the shrub.[5] Plantations were located in eight localities having climatic characteristics as shown in Table 1. In all localities the year is divided into wet winter and dry summer seasons. This study was largely restricted to variety 593, the best rubber yielder, and the one commonly used. The spacings, unless otherwise stated, were 28 inches between rows and 20 to 24 inches within rows. Computations were based upon the actual number of plants per acre. Both irrigated and dryland plantations were studied. Field work was conducted between January 15 and March 15, 1945, the season when the least change is taking place in rubber accumulation and the best period for comparative studies of rubber content.

Selection of the sampling sites was based on the uniformity of the soil type and profiles being studied. Shrub response to the following soil conditions was studied: (a) Good agriculture soils, (b) clay surface and clay subsoils, (c) sand and gravel surface and subsoils, (d) sand and gravel subsoils, (e) soils with claypans, (f) soils with hardpans, and (g) soils with high water tables. These are important and extensive soil conditions occurring throughout the guayule belt.

The study sites were of two kinds, (a) single and (b) paired. The single sites, designated *B checks*, were used to study guayule on a single soil type; the paired sites, designated *problems* and *A checks*, were used in fields containing closely associated soil types of different guayule growth potential. The paired sites were located as close to each other as was permitted by the uniformity of the two soil types—often as close as 15 feet and rarely more than 75 feet distant. This permitted comparisons under conditions as nearly similar in all respects as possible except for those differences represented by the two soils. Comparisons based on *B* checks may be less reliable than *A* check comparisons because of possible differences resulting from cultural treatments in different fields.

Each soil type in a plantation was studied at five randomized sites. At each site a temporary plot was established covering an area originally containing 20 plants. Crown dimension measurements, one vertical and two horizontal measurements at right angles, were made on each living plant. In a 100% stand, this permitted a maximum of 100 measurements for the five sites. Five plants, one from each site, with neighbors on four sides, were dug with roots 6 or 8 inches below the crown to simulate standard harvesting practices. These were weighed green, dried a few days, then composited into one sample and shipped to the

[5]The normal cycle is considered to be four to six growing seasons, but harvesting operations and termination of the government program made this earlier study necessary.

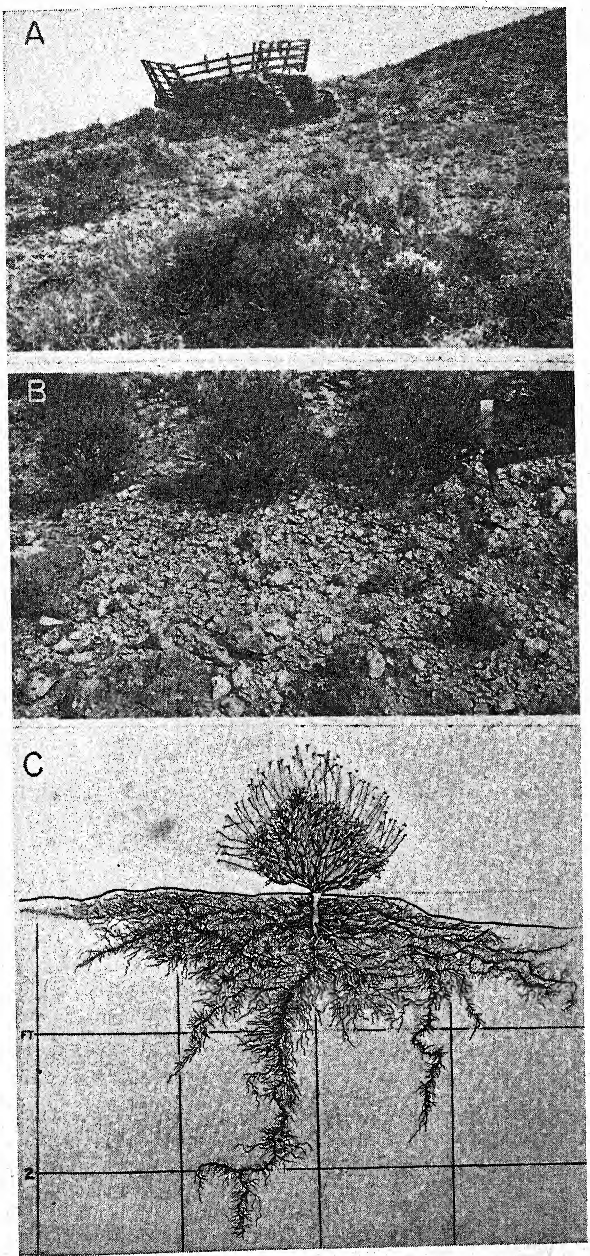

FIG. 1.—*A*, typical development of native guayule on foothill slopes near Fort Stockton, Tex. Note guayule bunched for harvest in foreground. *B*, shallow and stony soil of native sites. *C*, root- pattern of native guayule in stony soil.

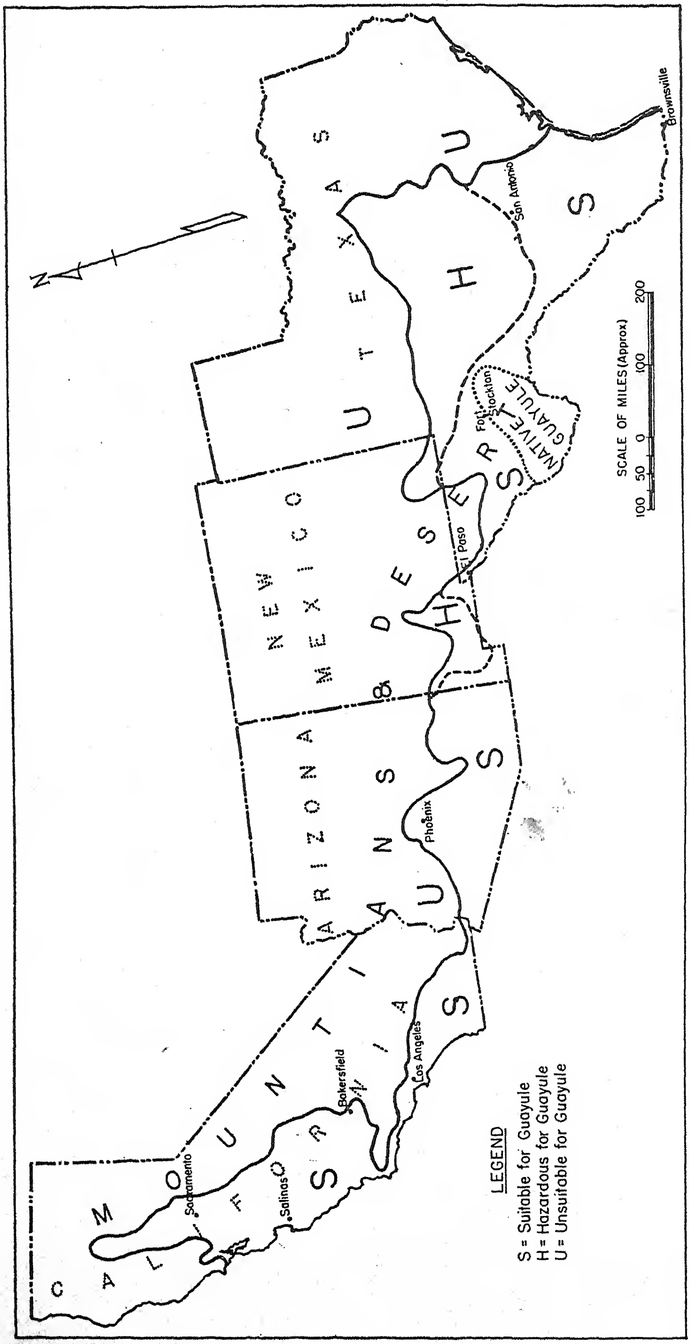

FIG. 2.—The guayule belt in the United States (temperatures and relief considered) and the locale of native guayule in the Big Bend region.

Rubber Analysis Laboratory of the Bureau of Plant Industry, Soils, and Agricultural Engineering at Salinas, Calif. There, rubber analyses were made and oven-dry defoliated weights obtained for each sample. All computations having to do with pounds of dry defoliated shrub and pounds of rubber per acre were based upon the average weight per plant from this five-plant composite sample. Survival percentages were used in computing the pounds of rubber per acre. Crown volumes represent an average of all living plants in the five sites.

Performance or yield comparisons in terms of pounds of rubber hydrocarbon per acre are expressed in terms of a "yield ratio", that is, the yields obtained on the best agricultural soils (*A* and *B checks*) are considered as 100 and the yields from problem soils are evaluated in terms of this unit. Performance was also measured by a comparison of crown volumes, pounds of dry defoliated shrub per acre, and percentage of rubber hydrocarbon.

RESULTS

Precipitation and temperature records in the localities where the field studies were made are shown in Table 1. These data are based upon the best records available and cover periods ranging from 10 to 83 years. The effective precipitation for 1942–43 and 1943–44, the two growing seasons of this study, are of significance in the dryland studies.

While the results obtained from this study do not lend themselves to statistical treatment, they do represent major differences in shrub size and yields which repeat themselves constantly. The comparative

TABLE 1.—*Climatic records in localities of field studies and effective precipitation for 1942–43 and 1943–44.**

Locality	Temperature, °F				Precipitation, inches			
	Mean maximum		Mean minimum		Mean annual	Effective av. annual†	Effective	
	Jan.	July	Jan.	July			1942–43	1943–44
Sacramento Valley:								
Chico	53.9	98.4	36.1	59.3	24.39	23.1	26.7	23.0
Arbuckle‡	52.6	94.0	37.8	60.0	20.14	—	14.2	13.1
San Joaquin Valley:								
Newman	56.1	97.3	35.6	59.1	10.46	9.2	8.1	7.7
Bakersfield	58.4	94.1	36.2	63.6	6.03	4.3	7.8	3.1
Coalinga	58.4	102.1	33.6	62.0	7.29	5.8	5.1	5.6
Central Coast:								
Salinas	60.1	70.6	38.5	52.4	13.99	14.0	14.6	13.6
King City	61.3	87.0	33.8	50.2	10.72	10.1	10.4	11.0
South Coast:								
Oceanside§	62.7	74.1	45.2	63.6	12.86	11.8	12.0	11.8
Beaumont¶	58.0	93.9	37.8	55.6	19.42	18.0	22.7	19.6

*Because of characteristic wet and dry cycle, computations are on basis of data from July of one year to July of the following year.

†Adjusted for temperature according to R. J. Russell's "Dry Climates of the United States", 1931. Salinas mean temperature of 56.4°F is used as base.

‡Precipitation for Dunnigan; temperature record for Colusa Station. Arbuckle is located midway between these two stations.

§Computed effective precipitation probably too low because of inadequate temperature records.

¶Temperature records for 4.5 years only.

TABLE 2.—*Some profile characteristics of the soils studied.*

Soil types and phases	Surface soil			Subsoil				Substratum		
	Thickness, inches	Drainage	pH	Thickness, inches	Texture,	Drainage	pH	Texture	Drainage	pH
				Good Soils						
Arvin* cosl and lfs†	18	M‡	4.7+	42	lfs	M	7.4+	—	—	—
Atwater* sl	13	M	7–7.4	19	sl	M	7–7.4	sl	M	7–7.4
Chualar cosl and l	16	M	7–7.4	26	cl, cos	M	7–7.4	lcos	M	7–7.4
Greenfield l	24	M	7–7.4	18	l	M	7–7.4	cosl	M	7–7.4
Hanford sl and sil	20	M	7–7.4	40	sl, sil	M	7–7.4	—	—	—
Hesperia fsl and sl	20	M	7–7.4	40	sl, fsl	M	7.4+	—	—	—
Moreno* vfsl, fsl, and l	22	M	7.4+	40	fsl, l	M	7.4+	—	—	—
Metz fsl	14	M	7.4+	46	fs, fsl	M	7.4+	—	—	—
Mocho l	17	M	7.4+	43	l, fsl, cl	M	7.4+	—	—	—
Ramona sl	16	M	6–7	20	cl, l	M	6–7	l	M	7–7.4
Sorrento fsl, cl, and l	15	M	7–7.4	15	cl, l	M	7.4+	cl, fsl	M	7.4+
Tehama* fsl	14	M	6–7	24	fsl, grfsl	M	6–7	grsl	—	7–7.4
Vina l and fsl	20	M	7–7.4	22	fsl, sil	M	7–7.4	fsl, sil	M	7.4+
Yolo l	28	M	7–7.4	20	l, cl	M	7–7.4	l, sl	M	7–7.4
				Clay Surface and Subsoils						
Ambrose sic	14	M-S	7–7.4	17	sic	S	7.4+	sic -cl	S	7.4+
Chaular c	20	M-S	7–7.4	16	c	S-M	7–7.4	c	M	7.4+
Lost Hills c	18	M-S	7–7.4	14	c	S-M	7.4+	grcl	M	7.4+

Sand and Gravel Surface and Subsoils										
Arvin* ls (s subsoil)	9	R	7.4+	51	s, & cos	VR	7.4+	—	—	—
Cortina* gls (gs subsoil)	10	R	7–7.4	50	gr & s	VR	7–7.4	—	—	—
Metz lcos (cos, s, g subsoil)	12	R	7–7.4	48	gr & cos	VR	7–7.4	—	—	—
Pleasanton gcl (g subsoil)	13	R	7–7.4	47	gr	VR	7–7.4	—	—	—
Sorrento lg (g subsoil)	14	VR	7–7.4	46	gr	VR	7–7.4	—	—	—
Sand and Gravel Subsoils										
Cortina fsl (g, s subsoil)	15	M	7–7.4	45	gr & s	VR	7–7.4	—	—	—
Hesperia sl (s subsoil)	25	M	7–7.4	35	s	VR	7–7.4	—	—	—
Hesperia cosl (cos subsoil)	29	M-R	7–7.4	31	cos	VR	7–7.4	—	—	—
Metz lfs (co s subsoil)	15	R	7–7.4	10	ls	VR	7–7.4	cos & gr	VR	7–7.4
Vina sl (s subsoil)	18	M	7–7.4	18	ls	R	7–7.4	—	VR	7–7.4
Claypans										
Bryant* l and cosl	13	M	7–7.4	21	c, sc	VS	7–7.4	cl, scl	S	7.4+
Corning l	16	M	6–7	20	c	VS	6–7	gr c	S	7–7.4
Esperanza* fsl	12	M	6–7	23	c	VS	6–7	gr c	S	7–7.4
Huerhuero l	16	M	7–7.4	22	c	VS	7–7.4	sc	VS	7.4+
Hardpans										
Exeter sl	10	M	7–7.4	16	hardpan	VS	7.4+	sl, scl	M	7.4+
High Water Tables										
Metz fsl	26	M	7.4+	36	fs, fsl, sil	M	7.4+	—	—	—
Salinas l	14	M	7–7.4	46	cl, fsl, fs	M	7.4+	—	—	—

*Tentative soil series name subject to change on correlation.

†Soil textures designated by code as follows: c = clay; si = silt; l = loam; s = sand; gr = gravel; co = coarse; f = fine; v = very.

‡Symbols describing drainage are designated as follows: M = Moderate; S = Slow; R = Rapid; V = Very.

differences obtained are of such character and magnitude as to represent reliable trends.

CHARACTERISTICS OF SOILS STUDIED

The wide variation in shrub size and in rubber content of guayule can generally be attributed to soil variations which influence the soil moisture regime. The most striking performance differences in this study were correlatable with soil characteristics which controlled or influenced the amount of soil moisture stress. Artschwager (2) has shown that manipulations of the water supply results in variation in both the percentage and the total pounds of rubber hydrocarbon produced. Most of the soils in the guayule belt have a moderate or high level of natural fertility; few can be considered poor for ordinary farm crops. Organic matter and nitrogen are commonly low or very low when compared with soils of the more humid regions. Most of the soils are calcareous or have a neutral reaction and a few are slightly acid in some horizons.

Sixty-one sites representing 34 soil types and 10 phases of soil types were studied. These soils represent seven of the major profile conditions which occur in the guayule belt. Some of the more important characteristics of the soils studied are shown in Table 2.

GOOD SOILS

A plantation on good soils—good in the ordinary agricultural sense of the word—will at 2 years produce a uniform stand of shrub having a height of about 18 inches and nearly closing the space between 28-inch rows (Fig. 3A). Crown volumes will commonly fall between 3,000 and 6,000 cubic inches (Table 4A). Heavily irrigated plants will be crowed, often matted, and the lower branches will be dead or dying from lack of sunlight. Soils of this nature have nearly ideal moisture relationships. Soil moisture data were obtained for nine of the good soils used in this study.[6] The average field capacity was 14.6%, the wilting point 6.2%, and the available moisture averaged 8.4%.

The total moisture applied to the several fields of good soils both as rainfall and irrigations is given in Table 3, together with the rubber hydrocarbon percentages and total pounds of rubber per acre for each field. The ability of the guayule plant to take advantage of favorable soil conditions is illustrated in Fig. 4A where maximum root penetration of this 2-year-old plant has reached 15 feet in Anthony loam.

Roots were found at 13 feet for 2-year plants in Hesperia sandy loam at Bakersfield in 1944. Depths of 19 feet in Sorrento loam and 15 feet in Delano sandy loam for 2-year plants have been reported.[7]

Data showing the response of both irrigated and nonirrigated shrub on good soils are given in Table 4A. These data show that both the percentage of rubber hydrocarbon and the pounds of shrub per acre varied much more in irrigated than in nonirrigated fields. Yields of

[6]Data from field work of E. J. Dortignac.
[7]See footnote 6.

TABLE 3.—*Total moisture applied by irrigation and rainfall to the fields of good soils.*

Location and field No.	Irrigations 1943		Irrigations 1944		Effective rainfall, 1943–44, inches*	Total moisture applied, inches	Rubber hydrocarbon	
	No.	Inches	No.	Inches			%	Lbs. per acre
Beaumont 3	3	15.0	2	10.0	19.6	44.6	8.63	487
Salinas 16-A	3	21.4	0	0	13.6	35.0	8.6	327
Salinas 16-C	3	20.4	0	0	13.6	34.0	9.08	358
Salinas 53-3	2	11.0	1	4.9	13.6	29.5	8.88	427
King City 58-C	2	15.9	2	12.0	11.0	38.9	11.75	430
King City 140-1B	5	41.3	1	9.8	11.0	62.1	6.28	367
Bakersfield 4-B	5	24.6	5	28.6	3.1	56.3	5.47	650
Bakersfield 16-A	5	28.6	4	39.4	3.1	71.1	3.34	351
Bakersfield 4	5	26.0	2	26.2	3.1	55.3	5.41	472
Bakersfield 1	6	54.0	4	41.0	3.1	98.1	6.17	490
Newman 40-5W	—	—	2	5.4	7.7	—	7.59	440
Newman 17	2	12.5	1	10.0	7.7	30.2	7.71	543
Newman 10-A	2	11.5	2	9.6	7.7	28.8	8.63	478
Newman 29	3	22.1	1	16.0	7.7	45.8	7.06	340

*From Table 1.

2-year irrigated shrub averaged 440 pounds of rubber hydrocarbon per acre, but the range in yields was from 327 to 650 pounds. Yields of nonirrigated shrub were 34% lower, averaging 289 pounds; the extremes ranged from 242 to 396 pounds an acre. The weighted average hydrocarbon percentage was 6.85 and 7.78 for irrigated and nonirrigated shrub, respectively. This suggests that irrigation practices affected plant behavior and lowered the rubber percentages. The four Newman plantations were the most consistent of all irrigated fields, all yielding 340 pounds or more with an average of 450 pounds an acre for all four. The Bakersfield shrub was consistently low in hydrocarbon percentage, but produced an average of 491 pounds of rubber due to the greater poundage of shrub grown.

Table 3 shows that the relationship between the quantity of water added and the percentage of rubber produced (large quantities of water-producing abundant shrub but a low rubber percentage) hold throughout except for Bakersfield 1 and King City 140-1B. With 98 inches of water Bakersfield 1 produced 6.17% or 490 pounds of rubber hydrocarbon per acre and King City 140–1B with 62 inches produced 6.28% or 367 pounds per acre. These trend reversals are due to unfavorable soil moisture relationships in the two fields. At Bakersfield lenses of sand and loamy sand occurred in the profiles, while at King City a thick layer of fine sand occurred below 30 inches. Both conditions were wasteful of water and probably produced stressed conditions similar to good soils receiving only 30 or 40 inches of water. Had either the irrigation frequencies or the amount of water added been less, the shrub would have suffered from drought and the yields would have been lower in both cases. Over-irrigation is illustrated by Bakersfield 16–A where 71 inches of water in nine applications on soils with a good moisture-holding profile produced only 3.34%

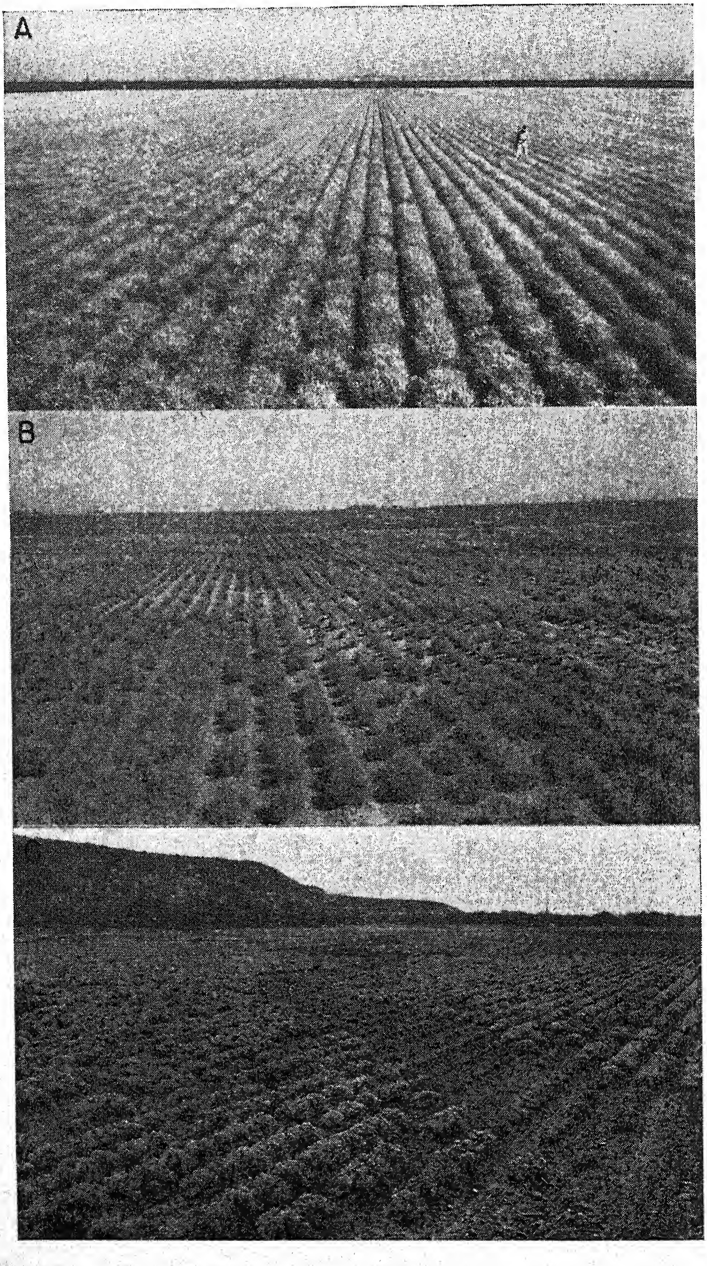

FIG. 3.—*A*, typical 2-year guayule on a good soil, Arvin loam, at Bakersfield. *B*, spotted condition of 2-year shrub due to hardpan subsoils of Exeter sandy loam, Bakersfield. *C*, typical appearance of shrub on soils with sand and gravel subsoils, Oceanside, Calif. The sand streak is not visible in the surface soils.

or 351 pounds of rubber. This field maintained a lush and nearly a continuous growth without the necessary intervening periods of stress.

In pounds of shrub and rubber hydrocarbon percentage, the nonirrigated plantations behaved similarly in all cases (Table 4A). The data suggest that the moisture stress of the shrub resulted in a high rubber percentage but a low shrub poundage and consequently a low final yield in total pounds of rubber.

Calculated yields of rubber based upon an assumed 100% stand (Table 4A) should be used with reservation, but they do form a base for comparisons where the factor of survival losses has been eliminated. Yields for 100% stands of irrigated and nonirrigated shrub on this basis averaged 513 and 356 pounds, respectively.

The data support the following conclusions for 2-year irrigated shrub: (a) Average yields were 52% greater than for nonirrigated shrub (b) Rubber hydrocarbon averaged (weighted) 6.85% but deviations were wide, reflecting the effect of different irrigation practices (quantity, time, and number of applications) on rubber production (c) Shrub weights varied widely and rubber hydrocarbon percentages were inversely related. Shrub yields below 4,000 pounds had a weighted average of 9.78% hydrocarbon, those between 4,000 and 7,000 pounds produced 7.82% and those above 7,000 pounds had a weighted average of 5.44% hydrocarbon. Intermediate shrub yields were most consistent in their accompanying rubber percentages; higher yields had wide differences in hydrocarbon percentages and the average of these percentages was low (d) Expected hydrocarbon yields at 2 years of age range between 350 and 650 pounds an acre under good management.

For nonirrigated shrub the data support the following conclusions: (a) Average yields were 34% below those for irrigated shrub (b) Rubber hydrocarbon averaged (weighted) 7.78% and deviations from this figure were narrow reflecting an overall physiological condition which was not greatly influenced by cultural treatments (c) Shrub poundage per acre commonly ranged between 3,000 and 4,000 pounds (d) Hydrocarbon yields for 2-year shrub on good soils can be expected to range between 250 to 400 pounds per acre.

CLAY SURFACE AND CLAY SUBSOILS

Clay soils are not well suited to guayule because of difficulty in seedling establishment, weed control, the high disease hazard, and poor internal drainage. Guayule may do well on very friable calcareous clays with good structure as is shown by the root distribution of 2-year shrub on Lewisville silty clay near San Antonio, Texas (Fig. 4B).

Geographically, and to some degree climatically, the three fields studied were far apart. The total inches of moisture added as effective rainfall and by irrigations were 35 and 20, respectively, for Salinas 53–2C and Newman 16. Records were incomplete for Patterson 40–5W. The results are given in Table 4B where comparisons are made with yields obtained on good soils from adjacent sites (A checks) or nearby fields (B checks). The weighted rubber percentage of 10.28

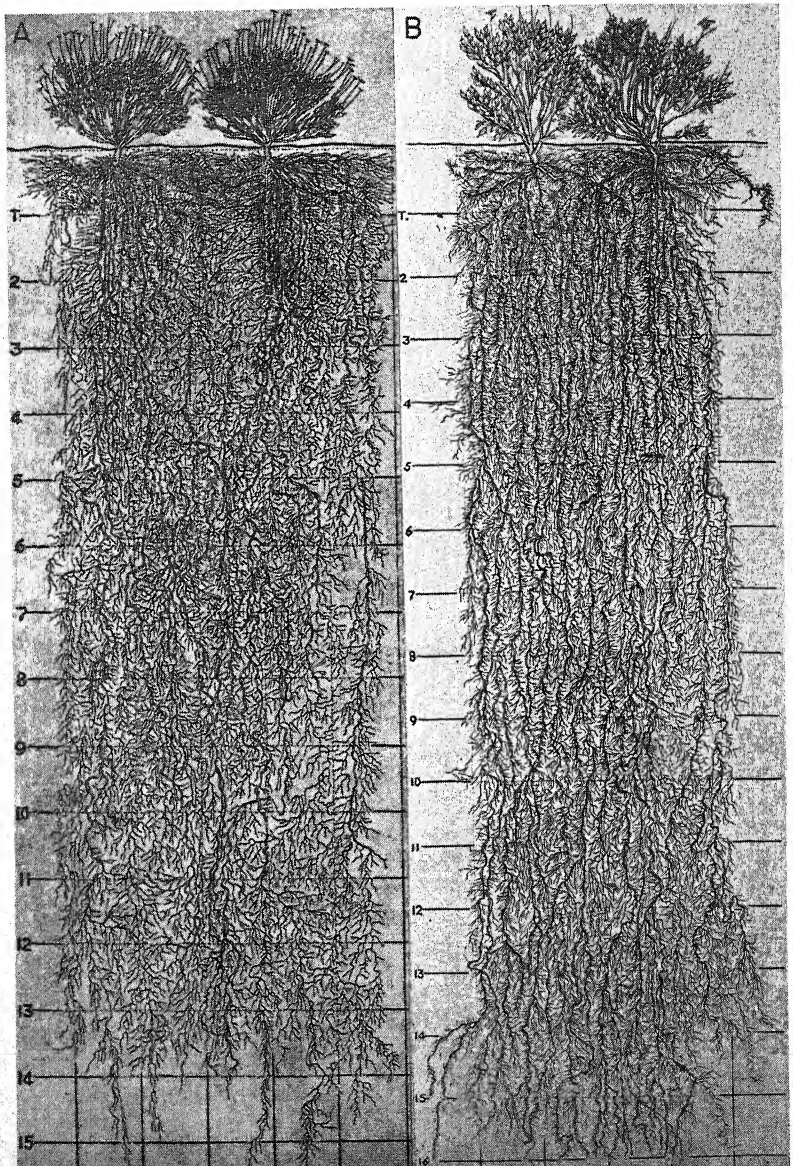

FIG. 4.—*A*, root distribution and penetration of 24-month irrigated guayule in Anthony loam near Phoenix, Ariz. *B*, root distribution of 25-month, nonirrigated guayule in a friable clay soil, Lewisville silty clay, near San Antonio, Tex.

is high and is 2 greater than the weighted average for the good soils used as checks. The hydrocarbon percentages for the three fields are strikingly similar. The shrub on clays had smaller crown volumes than the check shrubs on good soils, but wide differences existed in the pounds of shrub on the clays. With one exception the pounds of rubber produced were in favor of the good soils, the A and B checks, because of the greater shrub poundage produced. The exception, Newman 16, received more water than the other two fields, but this is not a recommendation for heavier irrigations on all clay soils, especially during the hot summer months when conditions favor disease development.

The data for irrigated 2-year shrub support the following conclusions: (a) Shrub on friable clay soils with good structure produce higher rubber percentages than shrub on good soils (b) Yields can be expected to range from 250 to about 600 pounds of rubber per acre but are commonly below yields on good soils (c) Heavier irrigations tend to produce more shrub, but on most clay soils tillage problems and probable disease losses would result from heavier water applications.

Field observations indicate that clay soils as a class should be avoided for guayule.

SAND AND GRAVEL SURFACE AND SUBSOILS

Where soils with sand and gravel surface and sand and gravel subsoils occur as small areas in fields of better soils, they cannot be given special cultural treatment. However, large uniform areas of sand soils occur within the guayule belt. They are characterized by very poor moisture relationships, the field capacity ranging from 5% to 7% and frequently only about one-half of this is available for crop use. They are often extremely infertile. Frequent irrigations are needed, and since the moisture is under low tension, a rapid and succulent growth results. The change-over from low to high moisture tensions is rapid and since the plant cannot make the necessary physiological adjustments to meet the extreme stress conditions, death or considerable damage results. The 2-year shrub is often small as shown by the crown volumes in Table 4C. In extreme cases, the shrub is hardly larger than one's fist.

The root distribution of 1-year irrigated guayule on Superstition sand is shown in Fig. 5A. The shallowness of the system and the coarse nature of the roots contrast sharply with those in good soils as shown in Fig. 4A and B. In the case of the King City 140–2ABC samples, maximum root penetration in four cases was found to be 25, 15, 21, and 17 inches. In all cases, it was observed that root penetration was related to the amount of fine soil material present.

Four of the fields in Table 4C were irrigated and received the following total amounts of water, including effective rainfall: King City 140–2A, B, C, 83 inches; Newman 10–A, 29 inches; Newman 29, 54 inches; and Bakersfield 1, 98 inches. The rainfall for the non-irrigated fields is given in Table 1.

The rubber percentages of the problem sites varied widely but were

TABLE 4.—*Comparative yields of 2-year guayule on different soils.*

Location and field No.	Soil type	Study	Survival, %	Dry defoliated shrub, lbs. per acre	Rubber hydrocarbon			Average crown volume per plant, cu. in.
					%	Pounds per acre*		
						Actual stand	Assumed 100% stand	
A—Good Soils, Irrigated								
Beaumont 3	Moreno† vfsl‡	——	80	5,643	8.63	487	609	4,619
Salinas 16-A	Chualar l	——	81	3,806	8.6	327	404	3,132
Salinas 16-C	Hanford si l	——	72	3,941	9.08	358	497	3,872
Salinas 53-3	Greenfield l	——	73	4,811	8.88	427	585	5,486
King City 58-C§	Chualar co sl	——	88	3,658	11.75	430	489	2,680
King City 104-1B	Metz fsl	——	71	5,849	6.28	367	517	5,071
Bakersfield 4-B	Hesperia fsl	——	97	11,882	5.47	650	670	9,379
Bakersfield 16-A	Hesperia sl	——	84	10,508	3.34	351	418	12,278
Bakersfield 4	Arvin† lfs	——	96	8,725	5.41	472	492	6,965
Bakersfield 1	Arvin co sl	——	96	7,943	6.17	490	510	5,306
Newman 40-5W	Mocho 1	——	87	5,791	7.59	440	506	4,965
Newman 17	Mocho l	——	90	7,047	7.71	543	603	4,434
Newman 10-A	Sorrento fsl	——	92	5,542	8.63	478	520	4,797
Newman 29	Sorrento l	——	95	4,815	7.06	340	358	3,514
A—Good Soils, Nonirrigated								
Beaumont 3	Moreno† vfsl	——	70	3,256	7.60	247	353	3,917
Beaumont 4	Hanford sl	——	93	3,184	7.89	251	270	3,346
Beaumont 4	Ramona sl	——	87	2,904	8.35	242	278	2,774
Newman 23	Sorrento cl	——	95	3,805	10.41	396	417	2,301
Arbuckle 16	Yolo 1	——	76	3,980	8.01	319	420	5,645
Chico 2	Vina l	——	81	5,157	6.03	311	384	4,134
Chico 1-1 & 3	Vina fsl	——	70	3,995	6.51	260	371	4,425

B—Clay Surface and Clay Subsoils, Irrigated								
Salinas 53-2C§	Chualar clay	Problem	87	3,210	10.56	339	390	2,718
Salinas 53-3	Greenfield l	B check	73	4,811	8.88	427	585	5,486
Newman 40-5W	Lost Hills clay	Problem	90	2,285	10.03	229	254	1,367
Newman 40-5W	Mocho l	A check	87	5,791	7.59	440	506	4,965
Newman 16	Ambrose si c	Problem	88	5,811	10.24	595	676	3,414
Newman 17	Mocho 1	B check	90	7,047	7.71	543	603	4,434
C—Sand and Gravel Surface and Subsoil, Irrigated								
King City 140-2ABC	Metz l co s (s & g subsoil)	Problem	84	1,097	10.96	120	143	405
King City 140-1B	Metz fsl	B check	71	5,849	6.28	367	517	5,071
Newman 10-A	Sorrento lg (g subsoils)	Problem	89	2,234	7.24	162	182	1,820
Newman 10-A	Sorrento fsl	A check	92	5,542	8.63	478	520	4,797
Newman 29	Pleasanton gcl (g subsoil)	Problem	89	1,572	7.75	122	137	704
Newman 29	Sorrento l	A check	95	4,815	7.06	340	358	3,514
Bakersfield 1	Arvin ls (s subsoil)	Problem	92	2,255	9.21	208	226	892
Bakersfield l	Arvin co sl	A check	96	7,943	6.17	490	510	5,306
C—Sand and Gravel Surface and Subsoil, Nonirrigated								
Arbuckle 16-C, D	Cortina gls (gs subsoil)	Problem	78	310	6.20	19	24	222
Arbuckle 16-C, D	Yolo l	A check	76	3,980	8.01	319	420	5,645
D—Sand and Gravel Subsoils, Irrigated								
King City 140-2ABC	Metz lfs (co s subsoil)	Problem	89	5,842	10.96¶	640	719	2,685
King City 140-1B	Metz fsl	B check	71	5,849	6.28	367	517	5,071
Bakersfield 4-B	Hesperia sl (s subsoil)	Problem	93	4,143	6.72	278	299	2,107
Bakersfield 4-B	Hesperia fsl	A check	97	11,882	5.47	650	670	9,379
Bakersfield 16-A	Hesperia co sl (co s subsoil)	Problem**	87	5,317	3.05	162	186	5,410
Bakersfield 16-A	Hesperia sl	A check**	83	11,947	2.18	260	313	13,871
D—Sand and Gravel Subsoils, Nonirrigated								
Arbuckle 16-C, D	Cortina fsl (gs subsoil)	Problem	81	788	6.51	51	63	560
Arbuckle 16-C, D	Yolo l	A check	76	3,980	8.01	319	420	5,645
Chico 1-1&3	Vina sl (s subsoil)	Problem	72	1,103	5.29	58	81	1,003
Chico 1-1&3	Vina fsl	A check	70	3,995	6.51	260	371	4,943

TABLE 4.—*Concluded.*

Location and field No.	Soil type	Study	Survivla, %	Dry defoliated shrub, lbs. per acre	Rubber hydrocarbon %	Rubber hydrocarbon, Pounds per acre*: Actual stand	Rubber hydrocarbon, Pounds per acre*: Assumed 100% stand	Average crown volume per plant, cu. in.
		E—Claypan Subsoils, Irrigated						
King City 58-C	Bryant co sl	Problem	89	709	12.97	92	103	458
King City 58-C	Chualar co sl	A check	88	3,658	11.75	430	488	2,680
		E—Claypan Subsoils, Nonirrigated						
Oceanside 6-C5B††	Huerhuero l	Problem	95	396	8.23	33	35	197
Oceanside 6-C1, C2††	Moreno l	B check	96	3,996	7.99	319	332	115
Arbuckle 18-C	Corning l	Problem	68	930	9.83	91	134	717
Arbuckle 16-C, D	Yolo l	B check	76	3,980	8.01	319	420	5,645
Arbuckle 13	Esperanza fsl	Problem	94	1,317	11.23	148	157	523
Arbuckle 13	Tehama fsl	A check	88	2,293	8.36	192	218	1,305
Salinas 3‡‡	Bryant l	Problem	74	887	14.03	124	168	1,005
Salinas 3‡‡	Chualar l	A check	82	4,911	12.19	599	730	5,791
		F—Hardpan Subsoils, Irrigated						
Bakersfield 34-C	Exeter sl	Problem	91	1,946	7.77	151	166	1,016
Bakersfield 34-C	Atwater† sl	A check	90	5,946	5.53	329	366	5,128
Bakersfield 4-B	Hesperia fsl	B check	97	11,882	5.47	650	670	9,379
		G—Permanent High Water Tables, Irrigated						
King City 140-1A§§	Salinas l	——	69	7,279	5.46	397	575	5,997
King City 140-1C§§	Metz fsl	——	81	10,883	5.0	544	672	4,343

*Divide by 0.7 to convert to pounds of crude milled rubber per acre.
†Tentative soil series name subject to change on correlation.
‡Soil textures abbreviated as follows: c = clay; si = silt; l = loam; s = sand; g = gravelly; v = very; f = fine; co = coarse.
§Shrub sampled for rubber analysis May 16, 1945.
¶Used rubber percentage figure obtained for sample King City 140-2ABC (Table 4C) which is possibly too high for this sample.
**Variety 407.
††One-year shrub.
‡‡Three-year shrub spaced 36 × 24 inches.
§§Plants spaced 28 × 12 inches.

relatively high in all cases, and in all cases were higher in those fields receiving the greatest number of irrigations. Drought is indicated by the small crown volumes and low pounds of rubber produced. Even assuming a 100% stand, the yields remain very low. An extreme case of drought may account for the behavior of Arbuckle 16–C, D where, contrary to all other studies, both the rubber hydrocarbon percentage and the shrub yields were low.

The data for these soils indicate that (a) rubber percentages are medium to high (average 8.79%) but, because of the small shrub, total yields are very low; (b) yields for 2-year irrigated shrub could be expected to range from 100 to 200 pounds an acre; (c) nonirrigated production on soils of this nature is impractical; (d) under irrigation, the quantity of shrub produced (likewise the rubber percentage)

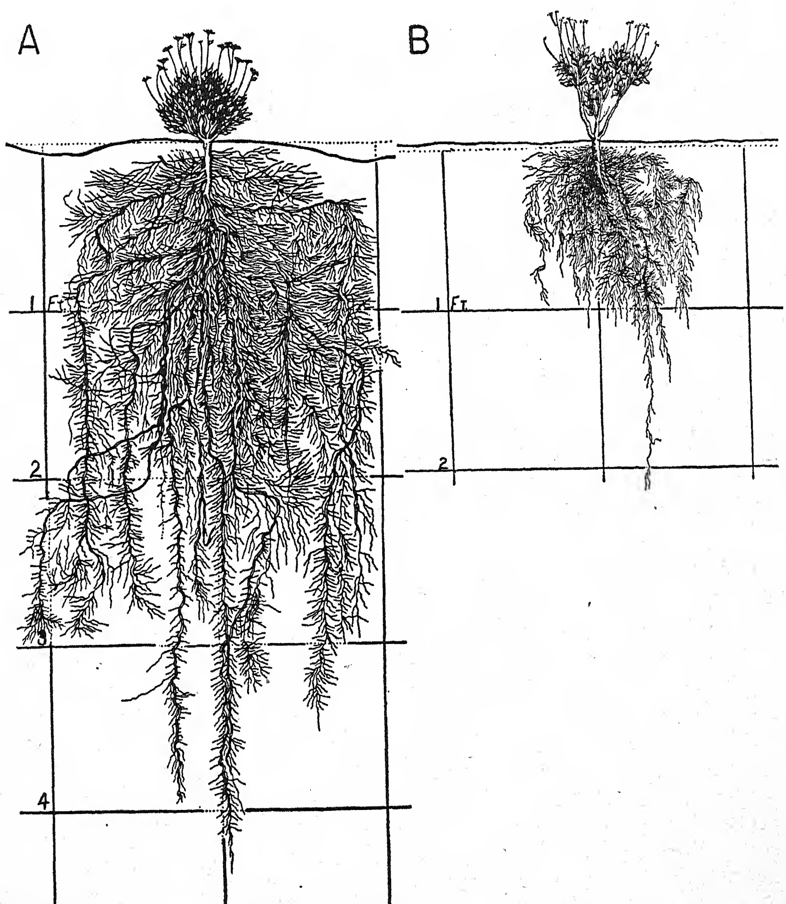

FIG. 5.—*A*, root distribution of 12-month irrigated guayule in Superstition sand near Yuma, Ariz. *B*, root distribution of 29-month nonirrigated shrub in Bryant loam with a strong claypan at 14 inches, near Salinas, Calif.

depends upon irrigation frequencies, but yields can never be large because of the impracticability of irrigating often enough.

Field observations indicate a high transplanting survival but subsequent losses.

SAND AND GRAVEL SUBSOILS

Soils with intermediate surface textures but sand or gravel subsoils are extensive throughout guayule belt, but rarely do they occur in large, continuous areas. Such soils are often artificially created by land leveling. Usually the surface soils have good or excellent moisture relationships and support vigorous plant growth, but the total moisture supply is limited and plants may suffer severely from the abrupt exhaustion of the supply.

Depending on the depth of the surface soils, 2-year irrigated shrub will have a height of 10 to 12 inches and a width ranging from 13 to 16 inches. Nonirrigated plants will range from 6 to 10 inches high and 8 to 12 inches in diameter. In the fields studied, instances were rare where guayule roots penetrated more than a few inches into the sand or gravel subsoils. Fig. 6A shows a typical root system in Hesperia sandy loam (sand subsoil). The surface layer is a sandy loam, the second layer a coarse loamy sand, and the third layer a coarse clean sand. The roots penetrate the loamy sand, but only 6 inches into the sand, a typical behavior. The plant in this case was 10 inches high and 14 inches in diameter. Observations showed that roots grew through sand lenses which were 6 to 8 inches thick, possibly during periods of low moisture tension.

Water was applied to the three irrigated fields—King City 14–2A, B, C, Bakersfield 4B and 16A—six, ten, and nine times, respectively, and the amount of moisture, including effective rainfall, was, in each case, 83, 56, and 71 inches.

In dealing with soils as irregular in their physical make-up as these, it could be expected that the results would also be highly irregular. In Table 4D the rubber percentages range from 3.05[8] to 10.96 as compared to 5.29 and 6.51 for the nonirrigated plants. The pounds of rubber produced likewise varied considerably and reached an extreme low in the nonirrigated fields. Pounds of shrub were much greater for the irrigated than for the nonirrigated fields due to the larger size of the irrigated plants.

The data support the following conclusions: (a) The wide variation in rubber percentages and yields for the irrigated shrub reflects differences in the physical properties of the several soils and the different irrigation practices. (b) Irrigated 2-year shrub could be expected to yield from 150 to 300 pounds of rubber per acre. (c) Nonirrigated 2-year shrub could be expected to yield from 20 to 100 pounds of rubber per acre.

Field observations indicate high transplanting survivals but subsequent losses.

CLAYPANS

Extensive areas of soils with claypan subsoils occur throughout the

[8]Variety 407 and possibly a low rubber-bearing strain.

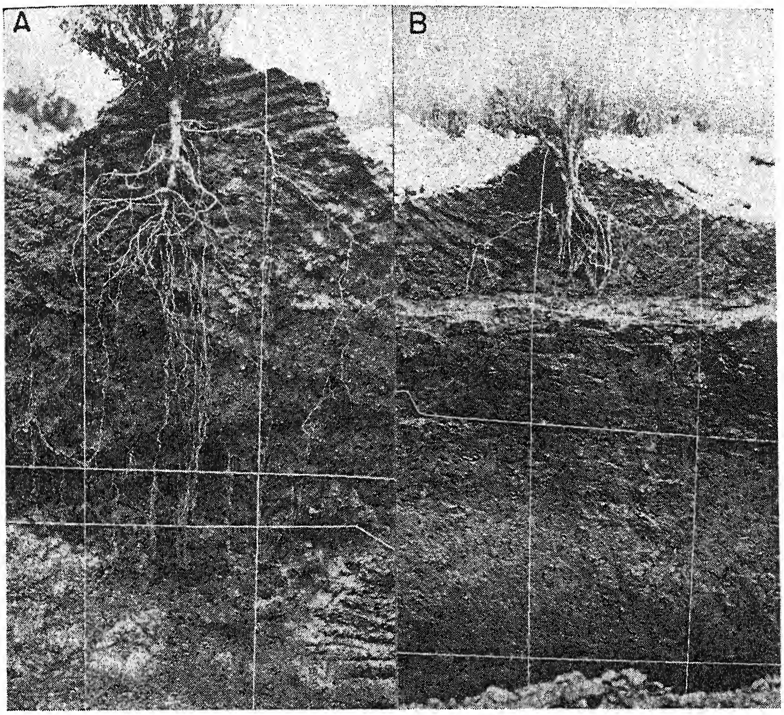

Fig. 6.—*A*, root distribution of 26-month irrigated guayule in Hesperia sandy loam (sand subsoils) near Bakersfield. *B*, root distribution of 24-month irrigated shrub in soils with hardpan subsoils, Exeter sandy loam, Bakersfield, Calif.

guayule belt. Poor internal drainage is an outstanding characteristic. Winter rains and heavy irrigations saturate the soil layers above the claypan resulting in death or severe damage to guayule roots. All the soils of this study have distinct claypans, but the Bryant and Huerhuero soils have the strongest developed claypans. Low fertility is characteristic of Esperanza, Corning, and to a lesser degree the Huerhuero soils.

The severe retarding effects of claypans are reflected in the small crown volumes of the shrub (Table 4E). One-year plants on Huerhuero loam were 6 or 7 inches wide and 5 or 6 inches high, while 2-year shrub on Esperanza fine sandy loam were 8 or 9 inches wide and 7 or 8 inches high. Root distribution of 3-year plants on Bryant loam in relation to a mottled, dense claypan at 14 inches is shown in Fig. 5B. Observations indicated that those plants which survived were usually able to penetrate the claypan with a few large, scantily branched roots, but these roots again branched after penetrating more favorable soil conditions below the pan. Dead and decaying roots above the claypan were abundant following periods of saturation. Root mortality depends upon the degree and endurance of the saturated condition

and upon previous adjustments of the root system to the unfavorable conditions. In some cases, a shallow lateral rather than a deep, spreading system enabled the plants to live. In most places, however, a high mortality rate accompanied the claypan.

Only one field, King City 58–C, was irrigated. Including effective rainfall and four irrigations, it received a total of 38.8 inches. The rubber percentages which were very high are shown in Table 4E. The small size of the plants reflects the small shrub poundage and low rubber yields. Compared with nonirrigated fields, the four irrigations did not increase the rubber yield on King City 58–C, and both the rubber percentage and pounds of shrub would indicate a degree of stress similar to nonirrigated shrub. Comparisons between nonirrigated 1-, 2-, and 3-year shrub indicate expected low rubber and shrub yields for the 1-year shrub, but an unexpected high rubber percentage. The high rubber percentages would indicate stressed, but slow, continuous growth. The dense claypan with a high moisture-holding capacity and a correspondingly high wilting percentage would supply moisture slowly and under relatively high tensions to feeding roots. Because few roots penetrate the claypan the rate of moisture supply would be very slow but constant throughout the growing season, thus creating the best possible condition for continuous rubber formation. At the same time this is incompatible with the growth necessary to obtain a high shrub tonnage and a high rubber yield. If extreme moisture tensions are detrimental to rubber accumulation (8), then for claypans in this study it must be assumed that the tensions were not of such extreme magnitude. This seems reasonable in view of the limited root penetration (Fig. 5B), and considering the probability that moisture was supplied the claypan from the deeper lying soil layers to which only a few roots penetrated.

The data indicate a high degree of rubber formation (weighted percentage of 11.51%) due perhaps to stressed but continuous growth. The same stressed condition results in very small shrub and a consequent low final yield. The data also show that the yields for nonirrigated and irrigated shrub can be expected to range between 20 and 200 pounds per acre at 2 years.

Field observations indicate a high shrub mortality occuring anytime between planting and harvest.

HARDPANS

Hardpans in the subsoils of some half million acres in the guayule belt are primarily responsible for those soils being unsuitable or of limited value for common farm crops and for guayule. In California these impervious sub-soil conditions occur largely in the San Joaquin, Madera, and Exeter soils. Following heavy irrigations and during the rainy season, the soils above the hardpans are saturated to a soupy consistency and often remain in that condition for long periods, except that the pan of the Exeter soils is often discontinuous, allowing internal drainage by lateral seepage.

Shrub on the Exeter soils has a common width of 9 or 13 inches and heights of 11 inches. The line of demarcation is abrupt between shrub

on good soils and that on soils with hardpan (Fig. 3B). Most of the roots are concentrated in the surface soil and are often matted on top of the hardpan where the most damage occurs from saturation. A few roots do penetrate the pan where seams and cracks occur, but they are thickened, heavy, and flattened. A root will develop and rootlets spread fan-like horizontally where a seam occurs until the space is occupied. Altogether, the percentage of roots penetrating the pan is small (Fig. 6B) and most of the moisture must come from the shallow surface soil. Frequent and light irrigations are necessary.

In the case of plantings on the Exeter soils, the original and subsequent survivals were good, but in the vicinity of Bakersfield, winter rainfall is normally inadequate to saturate the soil. The Exeter soils have a tendency to "slick over" and resist moisture infiltration. In belts of heavier rainfall, high mortality on hardpan soils could be expected and would occur anytime between planting and harvest.

One plantation, Bakersfield 34–C, was studied. It was given a total of 53 inches of water (3 inches of rainfall) in six irrigations. Moisture penetration in the hardpan areas was very slow and as a result those areas probably received considerably less moisture than the data indicate for the field as a whole. Only one set of studies were made, but field and shrub appearances over several hundred acres of Exeter soils were so similar to the sites studied that it is felt the results in Table 4F are representative. The rubber percentage of shrub on Exeter sandy loam is in the medium range and is higher than on most of the fields in the Bakersfield district. The shrub poundage and the small crown volumes emphasize the small size of shrub produced. This is characteristic of shrub grown under considerable moisture stress. Since the Atwater soil (A check Table 4F) is not as productive as the average good soil of the vicinity, the results of Bakersfield 4–B have been included (B check Table 4F) for comparison purposes.

The data suggest that yield of 2-year irrigated shrub on hardpan soils could be expected to fall between 100 and 200 pounds an acre. Yields from nonirrigated shrub could be expected to be more variable and possibly much lower. In areas of high winter rainfall a high shrub mortality can be expected and it may occur anytime between shrub establishment and harvest.

HIGH WATER TABLES

High and fluctuating water tables are found in restricted acreages throughout the guayule belt. They are created in many places by over irrigation or by seepage from irrigated areas at higher elevations.

The effect on guayule was studied in two fields where the water tables could be considered permanent, although the depths fluctuate in different seasons. Common plant sizes for King City 140–1A were about 17 to 19 inches wide and 15 to 17 inches high and for King City 140–1C 15 to 17 inches wide and 13 to 15 inches high. In the case of the former, the water table occurred between 48 and 60 inches; in the latter it was found between 82 and 108 inches. In no place were roots found below the moist fringe above the free water. Including rainfall, field 140–1A received 54 inches and field 140–1C 62 inches of water.

The rubber percentages were nearly equal (Table 4G) but were more than 3.5 lower than other common rubber percentages in the Salinas Valley on good irrigated soils. Likewise, the poundage of dry shrub was higher than for any other fields sampled in the entire valley. The water tables undoubtedly stimulated continuous growth without the benefit of intervals of summer stress and in this respect the plants behaved as would those under continuous heavy irrigations.

Water tables which came to or near the surface for a period of a few days or more during any part of the year could be expected to kill or severely damage guayule, but damage would occur more quickly during the hot summer months. From the meager data available it is probable that the total rubber produced would range from 350 to 600 pounds per acre for conditions where the water table remained 3 feet or more below the surface. Under these conditions, moisture is continually available under low tension.

DISCUSSION

EFFECT OF MOISTURE STRESSES

Rubber storage in guayule occurs in the living parenchyma cells of both stem and root (4). Artschwager (1, 2) has shown that rubber is laid down primarily in the parenchyma ray cells of the phloem and to a lesser degree in the xylem. It appears first in the parenchyma cells surrounding the resin ducts. Sclerenchymatization of the parenchyma cells reduces the potential storage space as likewise does a large complement of sieve tube tissue in the stems of certain varieties. Artschwager (2) showed that xylem tissue is differentiated early in the season (March in the Mesilla Valley) and its continued formation was favored by rapid growing conditions resulting from an abundant moisture supply. Rubber deposition in the xylem occurs late in the season (small amounts in late July) and much potential storage space is carried into the winter.

Phloem tissue differentiation begins late in the season coincidentally with flower stalk formation (late April). Cells of the current seasons growth begin to show rubber by July and are well filled by September with the coming of cool nights. Rubber deposition in the phloem in summer months is favored by recurring periods of moisture stress and Artschwager's work for 2-year plants on Gila silt loam indicated a slowdown period of 60 to 75 days was required before rubber deposition occurred in appreciable amounts under the conditions prevailing in his experimental plots. Continuous growth under low moisture tensions resulted in little rubber deposition in the phloem, and furthermore, the proportion of phloem to xylem tissue was reduced. Wadleigh, *et al.* (8) showed that rubber deposition peaks when the average moisture tensions are between 4 and 7 atmospheres. Conditions favoring maximum rubber deposition in the phloem did not produce a large shrub or high yields in pounds of rubber per acre in Artschwagers' experiments. Conversely, treatments favoring a large shrub tonnage produced low rubber percentages. The relationships between percentage rubber deposition, shrub tonnage, and moisture stresses were repeatedly demonstrated in this study.

Moderate to moderately strong soil moisture stresses can be assumed for the nonirrigated shrub on good soils (Table 4A) where a weighted average of 7.78% rubber was produced compared to a weighted average of 6.85% for the irrigated shrub. However, the tonnage and consequently the pounds of rubber per acre were considerably lower. As a group, irrigated Bakersfield shrub was low in rubber percentage but was high in pounds of shrub produced. The Newman shrub had both intermediate rubber percentages and shrub tonnages with moderate to high yields of rubber. These behaviors are correlateable with the irrigation treatments as shown in Table 3.

King City 140–1A and 140–1C (Table 4G) grew in fields with permanent high water tables and under low moisture tensions. Their rubber percentages were lower but pounds of shrub higher than for any other field in the Salinas Valley. Again, Bakersfield 16–A (Table 4A) with 71 inches of water produced shrub with 3.34% rubber which was 2.07% lower than any other shrub of the same variety in that vicinity. Likewise, it produced 10,500 pounds of shrub, a very high figure. Two other fields, Bakersfield 1 and King City 140–1B, received large amounts of water but their behavior, contrary to that normally expected, can be attributed to sandy layers in the soil which reduced the effectiveness of the water added.

That increasing or high moisture tensions results in increased rubber percentages has been pointed out (2, 3), but Wadleigh, *et al.* (8) suggest that very high levels of moisture stress should reverse this relationship. This suggestion is supported by three studies of nonirrigated shrub. Arbuckle 16–C, D (Table 4C) growing in gravel and sand produced 6.2%, or 1.81% less rubber than shrub a few feet away on good soils. About the same relationship held for another adjacent site (Table 4D) where the subsoils were gravel and sand. Again, Chico 1–1 & 3 (Table 4D) had severely stressed plants which were 1.22% lower in rubber than adjacent shrub on good soils.

That shrub growth with some moisture stress is harmonious with rubber deposition is shown by the shrub behavior on clay soils (Table 4B). The total water added for two of the fields was 30 and 35 inches. The rubber percentages were high and exceptionally uniform, indicating a condition favorable for phloem parenchyma formation and the continued deposition of rubber throughout the growing season. By fall the rubber percentage was already high and there was not the comparatively low summer increment followed by a large winter build-up which is characteristic of shrub grown on soils with low moisture tensions throughout the season. Shrub sampling in connection with other plantation studies support this explanation. Since clay soils normally retain considerable moisture at the higher tensions, it is probable that guayule can utilize a part of this moisture. In sandy soils the changes occur at rapid rates and before the plant can make the necessary physiological adjustment.

The behavior of shrub on soils with claypans and hardpans is similar to shrub on clays, but the shrub tonnage produced is very low with resulting very low rubber yields.

Practically, an operator must produce a large shrub with a high rubber percentage. For 2-year shrub on good soils, the Newman fields

(Table 4A) approached this. With 30 to 50 inches of water the Newman shrub produced 7% to 8.6% rubber and 4,800 to 7,000 pounds of shrub with yields commonly exceeding 450 pounds of rubber hydrocarbon an acre. To produce the necessary physiological condition in the shrub requires alternating periods of growth and moderate stress throughout the summer. This requires an irrigation cycle of 40 to 60 days on good soils but shorter intervals are needed on sandy soils and longer intervals on clay soils.

WINTER DEPOSITION OF RUBBER

It has been suggested that the best practice for irrigated shrub would be to produce a large vigorous plant with heavy summer irrigations and that the large amount of parenchyma tissue thus produced would be utilized by the plant for rubber storage during the dormant season. Such cultural practices result in a high proportion of xylem to phloem tissue, but rubber deposition in the phloem tissues will be great during the summer. Artschwager (2) pointed out that the large amount of xylem tissue is available for winter rubber storage, but for some reason the space is never fully utilized. In this study a similar behavior was observed. King City 140–1A and 140–1C (Table 4G) grew under low moisture tensions and produced a large tonnage of shrub in which it is assumed the woody or xylem tissue was larger in proportion to the phloem tissue than for plants grown under moisture stress. The rubber percentages were lower than for any other shrub in the Salinas Valley. Under conditions in Bakersfield which produced shrub in excess of 10,000 pounds an acre, the highest rubber percentage was 5.47 and the lowest 2.18. It would not seem advisable to produce a large tonnage of shrub under continued low moisture stress with the expectation that the rubber percentages would increase during the winter to equal those of shrub moderately stressed during the growing period.

PLANTATION PRODUCTION

On a plantation basis many variables other than soils influence the final yields obtained. Carefully controlled research into the variations of guayule growth and yield caused by soil conditions might yield more refined data than those presented here, but management of a particular field usually requires such latitude that those variables would have greater effect on crop yields than variations directly traceable to minor soil conditions. The practical operator could alter his cultural practices considerably with a knowledge of the principles involved in obtaining high rubber yields on soils of a given character. Certainly, it would be of great value to know beforehand that only poor rubber yields could be expected from soils of a given character even with a high level of management and that on other soils failures could be expected. In Table 5 yield comparisons are made between different soils by means of a "yield ratio" in which the yields from good soils are considered as 100. From these comparisons it is apparent that dry-land production on most of the problem soils is im-

practical. The irrigated production of shrub on excessively sandy and gravelly soils and soils with claypans or hardpans will probably result in yields ranging from 50% to 25% of the yields from good soils.

The different soil conditions have been grouped (Table 6) in three broad categories, namely, good, poor, and unsuitable, on the basis of pounds of rubber hydrocarbon expected from 2-year shrub. Cultural practices, especially under irrigation, will result in considerable variation, but the yield ranges are reasonable from the data available. The data do not justify the establishment of a greater number of suitability categories.

TABLE 5.—*Comparative yield ratios of 2-year guayule grown on problem soils and on good soils.*

Soil	Study	Yield ratios: Actual stand	Yield ratios: Assumed 100% stand
Clay Surface and Clay Subsoils			
Irrigated:			
Chualar clay	Problem	79	67
Greenfield loam	B check	100	100
Lost Hills clay	Problem	52	50
Mocho loam	A check	100	100
Ambrose silty clay	Problem	110	112
Mocho loam	B check	100	100
Sand and Gravel Surface and Subsoils			
Irrigated:			
Metz loamy coarse sand (sand and gravel subsoils)	Problem	33	28
Metz fine sandy loam	B check	100	100
Sorrento loamy gravel (gravel subsoil)	Problem	34	35
Sorrento fine sandy loam	A check	100	100
Pleasanton gravelly clay loam (gravel subsoil)	Problem	36	38
Sorrento loam	A check	100	100
Arvin loamy sand (sand subsoil)	Problem	42	44
Arvin coarse sandy loam	A check	101	100
Nonirrigated:			
Cortina gravelly loamy sand (gravel and sand subsoils)	Problem	6	6
Yolo loam	A check	100	100
Sand and Gravel Subsoils			
Irrigated:			
Hesperia sandy loam (sand subsoil)	Problem	43	45
Hesperia fine sandy loam	A check	100	100
Hesperia coarse sandy loam (coarse sand subsoil)	Problem	62	59
Hesperia sandy loam	A check	100	100
Nonirrigated:			
Cortina fine sandy loam (gravel, sand subsoil)	Problem	16	15
Yolo loam	A check	100	100
Vina sandy loam (sand subsoil)	Problem	22	22
Vina fine sandy loam	A check	100	100

TABLE 5.—*Concluded.*

Soil	Study	Yield ratios	
		Actual stand	Assumed 100% stand
Claypans			
Irrigated:			
Bryant coarse sandy loam	Problem	21	21
Chualar coarse sandy loam	A check	100	100
Nonirrigated:			
Huerhuero loam*	Problem	10	10
Moreno loam	B check	100	100
Corning loam	Problem	29	32
Yolo loam	B check	100	100
Esperanza fine sandy loam	Problem	77	72
Esperanza fine sandy loam	Problem	46†	37
Tehama fine sandy loam	A check	100	100
Yolo loam	B check	100	100
Bryant loam‡	Problem	21	23
Chualar loam	A check	100	100
Hardpans			
Irrigated:			
Exeter sandy loam	Problem	46	45
Exeter sandy loam	Problem	23†	25
Atwater sandy loam	A check	100	100
Hesperia fine sandy loam	B check	100	100

*Year-old shrub.
†A trurer evaluation for the vicinity is had by comparisons with the B check.
‡Three-year shrub.

The success of a guayule plantation may depend upon a high transplanting survival. In a number of cases, the nature of the soil plays an important role in establishment survival. The highest survivals can be expected from sandy and medium textured soils because of the ease of packing the soil around the roots. Considerable loss can be expected on clay soils because of the difficulty of obtaining a good planting bed. Weed control subsequent to planting is difficult because of the narrow moisture range over which clay soils can be cultivated and heavy rains anytime between planting and harvest may cause heavy losses from drowning, root rots, and other diseases. Original survival may be good on soils with hardpans or claypans, but heavy losses follow rains which saturate the surface soils above the subsoil layers.

GROUPING OF SOIL SERIES AND TYPES IN THE GUAYULE BELT

The more important soil series and types in the guayule belt are grouped in Table 7 according to their broad suitability for guayule, based on the findings of this study. The yields may have a wide range as a result of cultural practices, but they can be expected to fall within the limits summarized in Table 6.

If the guayule belt was divided on the basis of climatic differences likely to influence guayule culture, the following sections would stand out: (a) Sacramento Valley with heavy winter rainfall and hot, dry

TABLE 6.—*Ranges in yield ratios and pounds of rubber hydrocarbon for 2-year guayule under different soil conditions.*

Soil conditions	Irrigated		Nonirrigated	
	Yield ratios	Rubber produced, lbs. per acre	Yield ratios	Rubber produced, lbs. per acre
	Good		Good	
Good soils	——	350–650	——	250–400
High water tables (below 48 inches)	——	350–650	——	——
	Poor		Unsuitable	
Clay surface and clay subsoils (friable and well-drained)	50 to 100	250–600	——	——
Sand and gravel subsoils	45 to 65	150–600	15 to 25	20–100
Salts (slight amounts)*	45 to 50	150–200	——	——
	Unsuitable		Unsuitable	
Sand and gravel surface and subsoils	25 to 45	100–200	–10	20
Hardpans	25 to 45	100–200	——	——
Claypans	–30	——	10 to 30	20–200
Salts (moderate amounts)*	–40	60	——	——

*Data from a previously reported study (5).

summers—limited or no irrigation required; (b) California coastal valleys with medium winter rains and dry but cool and foggy summers —limited or no irrigation required; (c) San Joaquin and other interior valleys of California, all of Arizona, New Mexico, and west Texas to Pecos River—principally hot, dry desert with irrigation required; and (d) the Rio Grande Plain Region of southwest Texas, semiarid with rainy periods in May and September—no irrigation required. These divisions are recognized in Table 7, but data are not available to evaluate precisely the effects of these differences on rubber formation.

SUMMARY

A study was made of plantation-grown 1-, 2-, and 3-year guayule to determine the effect of a number of important soil differences on the yields obtained.

It was found that soil differences were dominat factors in influencing the pounds of rubber produced per acre. These differences were primarily associated with variations of soil moisture stress, a direct result of the soil moisture relationships of the types of soils studied. Lesser but important variations were associated with cultural treatments, particularly the frequency and quantity of irrigations.

The highest rubber percentages were produced by frequent and moderate periods of stress or slowdowns in the vegetative growth of the plant. An opposite condition resulted when the shrub was permitted rapid and lush growth under conditions of low moisture stress, but a much larger shrub tonnage was produced. The greatest yields

TABLE 7.—*Suitability of important soils for guayule in the guayule belt.*

Good soils	Poor soils	Unsuitable soils
Nonirrigated or Limited Irrigation *Sacramento and coastal valleys of California*		
Bellegrave* fsl† Chualar sl Columbia l Elkhorn sl Farwell gl Greenfield sl Hanford sl Lockwood l Metz fsl Salinas cl Sisquoc fsl Vina l Yolo l Zamora cl	All soils with loamy sand textures in surface or subsoils; slight salts; moderately sloping and erosive.	Claypans, moderate and strong amounts of salts; sand, gravel, or clay textures; steep slope, or erosive. Antioch l Artois* gsl Brentwood sic Bryant l Capay sic Corning gl Dublin c Huerhuero l Marina s Rincon cl
Rio Grande Plain Region		
Brennan fsl Delmita* fsl Duval fsl Encinal fsl Hidalgo fsl Laredo sil Uvalde cl Willacy fsl	Friable and silty clays, poorly developed claypans. Houston c Knippa* sic Montel sic San Antonio fsl Webb fsl	Sand or clay textures; claypans; moderate or strong salts, sloping or erodable; poorly drained soils. Devines* Martinez c Maverick c Monteola c Nueces s Orelia fsl Raymonville c Victoria c Wilson cl

Irrigation Required

San Joaquin and interior valleys of California

		Loamy sand textures, slight salts or poorly developed claypans.		Claypans, hardpans, moderate or strong salts, sand, or clay textures.	
Cajon fsl	Meloland fsl	Adelanto sl	Lost Hills l	Exeter sl	Merced sic
Chino cl	Mocho fsl	Hanford ls	Traver l	Imperial sic	Placentia sl
Esparto l	Moreno* fsl	Hesperia ls		Lethent c	Pond l
Foster fsl	Panoche fsl			Levis c	San Joaquin l
Hanford sl	Ramona sl			Madera l	
Hesperia sl	Sorrento cl				

Irrigation Required

Valleys of Arizona, New Mexico, and West Texas

		Soils with slight salts, loamy sand or silty clay textures, moderately developed claypans.		Moderate or strong salt concentrations, sand or clay textures, hardpans.	
Anthony sl	Mojave l	Casa Grande cl	Pima sic	Brazito s	Topaz l
Gila fsl	Papago sl	Higley cl	Karro l	Imperial c	Vinton lfs
Glendale sil	Tolleson l			Pinal l	
Laveen l	Mimbres l				

*Tentative soil series name; subject to correlation.
†Soil textures designated by code as follows: c = clay, si = silt, l = loam, s = sand, g = gravel, f = fine.

in pounds of rubber hydrocarbon per acre were obtained by growing the larger shrub with a lower rubber percentage, but this advantage may be considerably offset by increased irrigation, harvesting, and milling costs. This study indicated that the best compromise would be to produce a shrub having 7% to 9% rubber and 4,000 to 7,000 pounds of dry shrub at 2 years of age. On good soils, this is attained with the addition of 30 to 50 inches of water.

Under dry-land culture only moderate yields were obtained from the best soils; soils with unfavorable moisture relationships should not be planted to guayule.

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Lead Arsenate for the Control of Crabgrass[1]

F. A. Welton and J. C. Carroll[2]

UNDER some conditions lead arsenate, if properly applied, is an excellent control for crabgrass in lawns. The much publicized new weed control material 2,4-dichlorophenoxyacetic acid does not kill either the large crabgrass, Syntherisma sanguinale, or the small crabgrass, S. ischaemum. Crabgrass, therefore, remains the No. 1 problem in many lawns and in other areas of fine turf.

Some years ago it was found (7)[3] that 95% or more of the crabgrass in the lawn at the Ohio Agricultural Experiment Station was killed if lead arsenate was applied at the rate of 20 pounds per 1,000 square feet, providing the work was done during the fall or winter months previous to the first of March. Similarly, favorable results were obtained elsewhere in the United States, but in other localities failures were reported. In an effort to find the cause for this variation in performance, a research project was inaugurated the object of which was to determine why the results had been unpredictable.

HOW LEAD ARSENATE CONTROLS

The first step was to determine the manner in which lead arsenate controls crabgrass in those areas where favorable results had been obtained. A logical beginning in the research program, it was thought, would be to determine first, the active agent of control in the lead arsenate, whether the anion or the cation; and second, whether it killed the seedlings or the embryo of the seed.

Anion or cation.—To determine whether the anion or cation is responsible for the control, lawn areas badly infested with crabgrass on the campus of the Ohio Agricultural Experiment Station (Wooster silt loam) were treated with various salts each containing one or the other radicle but not both. The chemicals used were calcium arsenate, manganese arsenate, arsenic pentoxide, and lead acetate. The latter gave no control, but all of the others did and inasmuch as the acid radicle is the only property they have in common it follows that the anion in lead arsenate is the active agent.

Seedling or seed.—To determine how the lead arsenate controls, that is, whether it kills the tiny crabgrass seedlings or the seed itself, it was applied to a new seeding of crabgrass—made in midsummer when both moisture and temperature conditions were favorable for prompt germination of seed. In this test little or no control was obtained, thus indicating that the arsenate does not act on the seedlings. Since crabgrass seed germinates promptly under favorable conditions, it is conceivable that the seedlings may have become established before any breakdown occurred in the lead arsenate.

In another test turf badly infested with crabgrass seed was treated

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication January 2, 1947.

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[3]Figures in parenthesis refer to "Literature Cited", p. 520.

with lead arsenate in the early spring before the temperature was high enough to permit germination. With the coming of suitable temperature and moisture conditions for the germination of crabgrass seed, a good stand of seedlings developed, thus indicating that lead arsenate does not kill the seedlings. In the following season, however, practically no crabgrass plants appeared on this treated area. The assumption, in this and in other similar situations, is that in order for lead arsenate to control crabgrass it must lie in contact with the seed for a considerable time during which it gradually breaks down and the poison penetrates the seed coat and eventually kills the embryo.

In a laboratory test, positive evidence on the killing effect of lead arsenate on crabgrass seed was obtained. Two lots of crabgrass seed were placed in separate petri dishes between two moistened filter papers and left at a temperature subnormal for germination for a period of 3 weeks. One lot at the beginning was treated with lead arsenate at the rate of 20 pounds per 1,000 square feet and the other lot left untreated. At the end of this period the treated seeds were washed free of lead arsenate after which both lots, untreated and treated, were placed under conditions favorable for germination. At the beginning, and at 2-hour intervals thereafter, seeds from both lots were fixed and imbedded in paraffin preparatory to sectioning.

Later, longitudinal sections were made on both series of imbedded material, the untreated and the treated. These revealed that growth of the embryo had been initiated by the time the seed had been in the germinator 18 hours in the case of the untreated or check material, but at the same hour no development had occurred in the embryo of the seed previously treated with lead arsenate. In fact in the latter no growth had taken place at the end of 72 hours. Apparently the lead arsenate had killed the embryo. The results were as shown in Fig. 1.

SOIL IS A FACTOR

Having determined that lead arsenate kills the seed of crabgrass, the next step was to find out why the results heretofore had been unpredictable.

The most probable explanation seemed to be that in some soils there may be elements or compounds which react with or fix the arsenic as it becomes available in the gradual breakdown of the lead arsenate and thereby inhibits its action.

To study this possibility, a soil (Wooster silt loam) on which lead arsenate was known to give excellent control of crabgrass was treated with various salts prior to the application of lead arsenate in order to determine if any of them interfered with the effectiveness of the lead arsenate treatment for the control of crabgrass. Two series of experiments were conducted, one in pots in the greenhouse and one outside on a portion of the Station campus abundantly infested with crabgrass seed.

Greenhouse tests.—Thirty 4-inch glazed pots were filled with Wooster silt loam soil. These were divided into six lots of five jars each. Four of these lots were pretreated before the lead arsenate was applied. These pretreatments were as follows:

Lot 1. Calcium carbonate, 184.00 lbs. limestone per 1,000 sq. ft. (8,000 lbs. per acre)

Lot 2. Ferrous sulphate, 13.75 lbs. copperas per 1,000 sq. ft. (600 lbs. per acre)

Lot 3. Phosphorus, 45.90 lbs. 20% superphosphate per 1,000 sq. ft. (2,000 lbs. per acre)

Lot 4. Nitrogen, 70.00 lbs. Soybean meal per 1000 sq. ft. (3,000 lb. /A)

Lot 5. No pretreatment; lead arsenate later.

Lot 6. No pretreatment; no lead arsenate later.

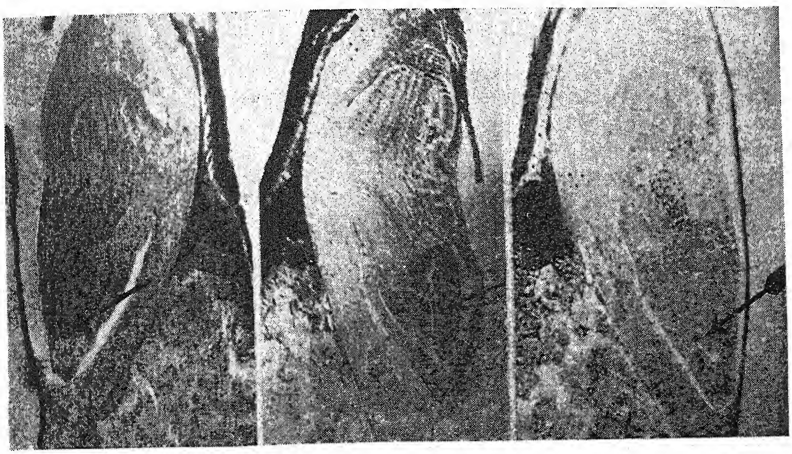

FIG. 1.—Longitudinal section through the embryo of three crabgrass seeds. *Left*, normal or check; *center*, not treated with lead arsenate but after having been exposed to conditions favorable for germination for 18 hours at 25° C; *right*, treated with lead arsenate and stored at 5° C for 3 weeks after which it was placed in a germinator at 25° C for 72 hours. ×800. Note developing plumule in center seed and absence of it in right seed, the latter remaining the same as in the check (left).

The materials used for pretreatments were worked into the surface of the soil, after which the soil was moistened and all the pots were left in the greenhouse for about 1 month. At the end of that time they were planted with seeds of large crabgrass. In addition, lead arsenate was applied at the rate of 20 pounds per 1,000 square feet to the four lots of pretreated pots as well as to lot 5 which had not been pretreated. To facilitate even distribution, the poison was mixed with sand half and half. All pots were then placed in an unheated room and allowed to remain there throughout the winter months each being moistened, if necessary, from time to time to keep the surface from becoming dry. With the coming of warm weather all the jars were returned to the greenhouse where conditions were favorable for the germination of crabgrass seed.

In this test the efficacy of the lead arsenate was in all cases reduced; more by some of the materials than by others. The inhibiting effect of calcium carbonate and of nitrogen was about the same, but in both

cases it was considerably less than with either of the other two materials—ferrous sulphate or phosphorus. The results should be regarded as indicative only and not as conclusive, for if each material had been applied in larger quantities the results might have been much more pronounced. The addition of much more than 4 tons of limestone per acre to the Wooster silt loam would be required to make it comparable in calcium content to what is usually characterized as a "limestone soil". Neither would the addition of 1½ tons of soybean meal per acre transform it into one comparable in content of nitrogen and organic matter to dark loam soils—a kind on which lead arsenate is rarely effective. The inhibiting effects of ferrous sulfate and phosphorus were quite marked. Again, it is probable that heavier applications would have given more pronounced results. The nullifying effects of the pretreatments with calcium carbonate, ferrous sulfate, and phosphorus were as shown in Fig. 2.

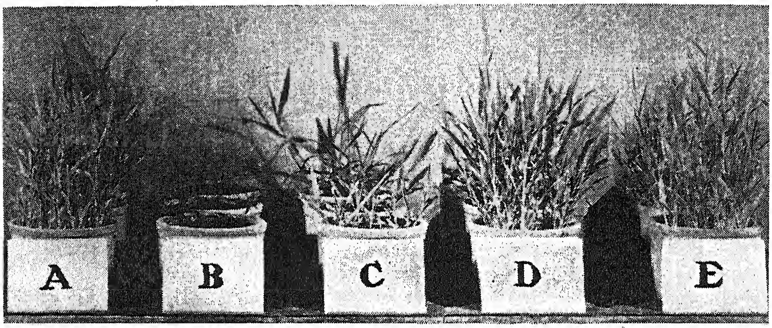

FIG. 2.—Lead arsenate gives good control of large crabgrass on Wooster silt loam soil, but its effectiveness can be materially reduced by pretreatment with various materials. *A*, no treatment (check); *B*, lead arsenate alone; *C*, lead arsenate preceded by calcium carbonate; *D*, lead arsenate preceded by ferrous sulfate; and *E*, lead arsenate preceded by phosphorus.

Campus tests.—A similar experiment was conducted on a portion of the campus badly infested with crabgrass. In this test, plots (5 x 5 feet) were pretreated with calcium carbonate, ferrous sulfate, phosphorus, and nitrogen each in the same form and at the same rate as used in the greenhouse test. The pretreatments were made in November and about a month later lead arsenate was applied at three different rates—15, 20, and 25 pounds per 1,000 square feet. Three tests of this kind were conducted, each in a different year. In all three years it was evident that more crabgrass plants developed on the pretreated than on the non-pretreated plots. In one year a count of the crabgrass plants was made. The results of this count were as shown in Table 1.

In Table 1 it may be noted that the number of crabgrass plants was reduced by the lead arsenate and the heavier the application the greater the reduction. Averaging the stand from the three rates of treatment, it may be seen further that the effectiveness of the lead

TABLE 1.—*Number of crabgrass plants per 1,000 square feet on plots treated with lead arsenate following various pretreatments.*

Pretreatment		Number of crabgrass plants per 1,000 sq. ft.				
Material used	Pounds per 1,000 sq. ft.	Pounds lead arsenate per 1,000 square feet				No lead arsenate, no pretreatment
		15	20	25	Average	
Nothing..........	——	1,840	1,520	1,320	1,560	4,480
Calcium carbonate	184.00*	2,480	1,760	2,360	2,260	4,440
Ferrous sulfate....	13.75	4,880	3,520	4,640	4,347	4,860
Phosphorus.......	45.00†	4,200	3,600	4,280	4,027	4,080
Nitrogen.........	70.00‡	3,080	2,160	2,920	2,720	4,180

*Limestone. †20% superphosphate. ‡Soybean meal.

arsenate was reduced by all of the pretreatments; less by the calcium carbonate and nitrogen than by the ferrous sulfate and phosphorus. In fact where the latter two were used the effectiveness of the lead arsenate was almost *nil*. This is shown by comparison of the average stand with that given in the right hand or check column.

In this particular experiment more crabgrass occurred on the plots treated with lead arsenate alone (no pretreatment) than is the usual experience on the Wooster silt loam. In field experimental series of other seasons lead arsenate, particularly at the higher rates, practically eliminated crabgrass from the turf. Moreover the effect persisted for several years.

In view of the results obtained through these various pretreatments certain other observations and experiments are pertinent to record at this point.

TYPES OF SOIL OTHER THAN WOOSTER SILT LOAM

Some years ago during the course of a tour of inspection of turf plots under the supervision of the U. S. Golf Association, Green Section, in and near Washington, D. C., two areas were observed both of which had been treated with lead arsenate to control crabgrass. One was comparatively free of crabgrass, the other was not. The chief difference between these two soils, so far as their properties were noted (Table 2), was in the content of soluble iron, nitrogen, and organic matter.

The plot on which lead arsenate gave little or no control had a higher content of calcuim, phosphorus, and iron, particularly soluble iron. In Table 2 it may be noted also that this plot was considerably higher, too, than the Wooster silt loam in the three constituents mentioned.

A trial was reported from Trenton, Ill., to the effect that lead arsenate failed to control crabgrass there. As shown in Table 2, the Illinois soil contained practically the same quantity of soluble iron as the Wooster silt loam but over three times as much soluble calcium and phosphorus, two times as much clay, and somewhat more nitro-

TABLE 2.—*Control of crabgrass with lead arsenate in relation to certain soil properties.*

Source of soil	Degree of control	Percentage of					
		Soluble			Nitrogen	Organic matter	Clay
		Ca*	Fe*	P*			
Wooster, Ohio	Good	0.135	0.099	0.007	0.106	2.17	9.5
Washington, D. C.	Poor	0.080	0.191	0.003	0.194	3.90	10.3
Washington, D. C.	Good	0.120	0.053	0.003	0.115	2.30	11.4
Trenton, Ill.	Poor	0.420	0.083	0.023	0.154	3.20	20.0
Madison Co., Ohio (dark)	Poor	0.740	0.078	0.021	0.378	7.33	18.5
Madison Co., Ohio (light)	Good	0.160	0.091	0.008	0.128	2.47	12.2

*Soluble Ca, Fe, and P were made on N/5 Hcl extract, using for Ca the A.O.A.C. volumetric method; for Fe, a colorimetric o- Phenanthroline method (5); and for P, a colorimetric method (8) where lead arsenate had not been applied and the A. O. A. C. gravimetric where it had been used.

gen and organic matter. It is conceivable that the quantity of clay may be an inhibiting factor in the action of lead arsenate on seed of crabgrass, due to its relatively high content of colloids.

To study further the effectiveness of lead arsenate on soils of different types, samples were collected from four outlying experimental farms in Ohio—one each in Cuyahoga, Madison, Miami, and Paulding counties.

The soil on the Cuyahoga County farm (Strongsville) is known as Mahoning silty clay loam and that on the Paulding County farm as Paulding clay. On both the Madison and Miami County farms there are two distinct soil types—Brookston (dark) and Miami (light). From the four farms six types of soil were gathered. These included the two types, Brookston and Miami, on both the Madison and Miami County farms.

Sixty 5-inch glazed pots were filled with these six types of soil, 10 pots with each type. Seed of large crabgrass was sown on all the pots and a half of each group (5 pots) was treated with lead arsenate at the rate of 20 pounds per 1,000 square feet after which all the pots were moved to an unheated room where they remained through the winter months. They were watered from time to time to keep the soil moist. With the coming of warm weather all the pots were returned to the greenhouse and placed under conditions favorable for germination. In due time crabgrass plants developed. The difference in results obtained on the two types of soil, dark and light, from the Madison County farm were quite marked, as shown in Fig. 3. From this figure it may be noted that the lead arsenate was highly effective on the light but not on the dark soil. Furthermore, reference to Table 2 reveals that the composition of the light soil was quite similar to that of the Wooster silt loam. On the contrary, the dark soil, with the exception of the soluble iron, differed from both in that it contains a much higher content of calcium, phosphorus, nitrogen, organic matter, and clay.

The results obtained on the other four types were inconclusive but

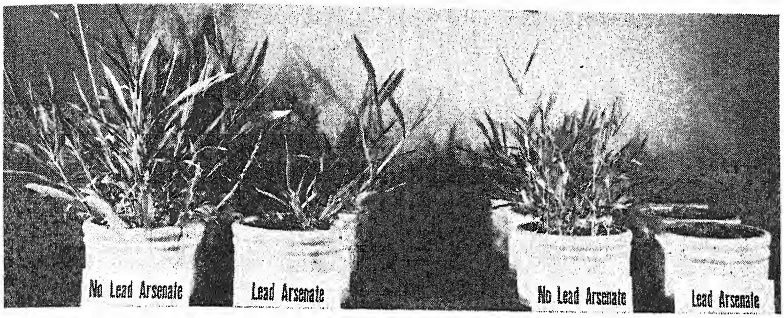

FIG. 3.—Effectiveness of lead arsenate in the control of large crabgrass on two types of soil, dark (left) and light (right) from the Madison County Experiment Farm.

further prosecution of work on the project was discontinued on account of the exigencies of the war.

DISCUSSION

As already indicated, lead arsenate usually gives good control of crabgrass on the Wooster silt loam. This is true providing the material is applied at the rate of 20 pounds per 1,000 square feet any time through the winter before March 1, and if the soil during that time is reasonably moist. One objection urged against the use of lead arsenate is its relatively high cost. This point, however, loses much of its weight in view of the fact that this material is frequently used regardless of whether crabgrass is a problem to combat various animal pests found in turf such as white grubs, moles, and Japanese beetles.

Another and more serious drawback to its use is the fact that the results have been unpredictable. In some of the early trials they were positive, in others negative or indifferent. The results presented in this paper indicate that the variability is correlated, in part at least, with the composition and types of soil; and that the effectiveness is reduced, or perhaps nullified altogether by the presence in the soil of relatively large quantities of certain chemical elements such as calcium, iron, and phosphorus and possibly of colloidal material.

The reduction in effectiveness of lead arsenate from the use of ferrous sulfate, probably resulted from a conversion of some of the arsenic from a soluble to a less soluble form. This would be in agreement with the work of Vandecaveye, Horn, and Keaton (6), who in studying the unproductiveness of certain soils from which 27-year old apple trees formerly sprayed with lead arsenate had been removed, found a close correlation between unproductivity and content of soluble arsenic in the tops and roots of barley and that the toxicity was reduced by the addition of ferrous sulfate and to a lesser extent of copper sulfate and calcium carbonate.

The preliminary results on different types of soil in which it was shown that lead arsenate was less effective on heavy than on light soils were probably due, in part at least, to the fact that soil colloids

are more abundant in the former than in the latter types and that these fix the soluble arsenic as fast as it becomes available and thus render it ineffective as an agent for killing crabgrass seeds. Gile (3) concluded that soil injury from the use of calcium arsenate depends on the quantity of colloids it contains. Dorman and Coleman (1), Dorman, Tucker, and Coleman (2), and Reed and Sturgis (4) reported that the use of calcium arsenate affected adversely the productivity of sandy soil to a greater extent than it did heavy soil.

SUMMARY

1. In the control of crabgrass with lead arsenate, the active agent in the salt is the anion.

2. The arsenic kills not the tiny seedlings, but the embryo of the seed.

3. In a greenhouse pot test using Wooster silt loam the effectiveness of lead arsenate as an agent for the control of crabgrass was reduced by pretreating the soil with calcium carbonate, ferrous sulfate, phosphorus, and nitrogen; less by the calcium carbonate and nitrogen than by the ferrous sulfate and phosphorus. In case of the latter two the reduction in effectiveness was marked.

4. In a second test conducted outside on the Station campus using the same pretreatments as in the greenhouse test and in the same quantities and with lead arsenate at the rates of 15, 20, and 25 pounds per 1,000 square feet, the results were similar to those obtained in the greenhouse test.

5. In tests at Washington, D. C., the soil on which lead arsenate gave poor control of crabgrass ran markedly higher in soluble iron and considerably higher in nitrogen and organic matter than did the one on which fairly good control was obtained.

6. Soil from Trenton, Ill., on which no control was obtained with lead arsenate differed from the Wooster silt loam in that it contained over three times as much soluble calcium and phosphorus, two times as much clay, and considerably more nitrogen and organic matter.

7. On two types of soil from Madison County, Ohio, lead arsenate gave good control of crabgrass on a light soil (Miami) but poor control on a dark soil (Brookston). The Brookston soil differs from the Miami in that it contains over four times as much soluble calcium, nearly three times as much soluble phosphorus, almost three times as much nitrogen and organic matter, and one and one-half times as much clay.

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Weeping Lovegrass, *Eragrostis curvula,* Seeding Test Results in the Copper Basin[1]

W. H. CUMMINGS[2]

WEEPING lovegrass, *Eragrostis curvula,* is an introduction from South Africa that in the past decade has shown promise for a diversity of uses in the southern United States. The habitat, characteristics, soil conservation uses, and culture of this grass have been covered in an excellent monograph by Crider[3]. A special problem is presented in the re-establishment of good vegetation cover in the Copper Basin of southeastern Tennessee—a unique man-caused desert in the forest of the humid mountainous region of the East. Here, studies on what reforestation practices are effective for controlling erosion were initiated in 1941 by the Tennessee Valley Authority. Results of test seedings of weeping lovegrass on severely eroding land in the Copper Basin are reported upon.

THE PLANTING CHANCE

The Copper Basin is a 23,000-acre deforested and eroding area. It has been laid waste since mining began a century ago by smoke from copper smelting, destructive logging, fires, and grazing. Natural revegetation has been lacking generally; even during recent years marked by abatement of smoke and aroused interest in reforestation and protection. Virtually enclosed by high land with good forest cover, the Copper Basin is characterized by roughly concentric zones of varied land condition. Transition inward is from slight to severe erosion, and from scrubby growth of hardwoods, chiefly post oak, to grass cover dominantly of yellowsedge bluestem or broomsedge. In the center of the basin, 4,000 acres of severely eroding land lacking vegetative cover presents an erosion-control planting chance of unusual difficulty (Fig. 1). Chief adversities of site are accelerated soil erosion, heavy rainfall, excessive exposure to climatic extremes such as cold or hot drying winds, and occasional injurious concentrations of sulfur dioxide in the air. To control erosion on these sites, protective plant cover is needed to fix the soil until tree plantings become established.

COMPARATIVE TESTS OF COVER PLANTS

In 1941, the TVA Forestry Relations Department initiated studies to adapt erosion-control planting practices which had been applied extensively in the Tennessee Valley to the special adverse sites in the Copper Basin. Economical experiments were designed to test establishment of ground cover plants. Areas selected for these experiments are representative of the adverse conditions in the denuded

[1]Contribution from Tennessee Valley Authority, Forestry Relations Department, Forestry Investigations Division, Norris, Tenn. Received for publication January 16, 1947.

[2]Forester, in charge, Forest Products Section.

[3]CRIDER, FRANKLIN. Three introduced lovegrasses for soil conservation. U.S.D.A. Circ. 730. 1945.

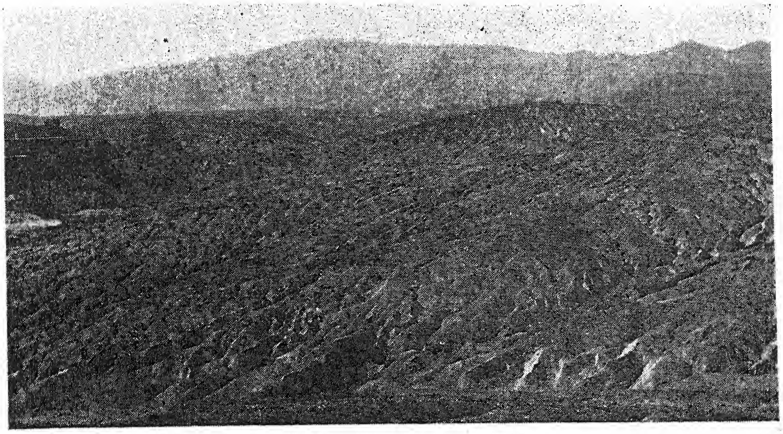

FIG. 1.—Land in the center of the Copper Basin is bare and severely eroded. This planting chance of 4,000-acre extent requires intensive treatment for erosion control.

zone of the basin except that they were fenced for protection against open-range stock. Experimental areas are at three separate locations; near Copperhill, near Isabella, and near Ducktown[4]. Test plots were laid out on ridgetop sites that are above the deep gullies but are subject to rapid surface erosion. The exposed mineral sub-soil of Hayesville loam tests strongly acid, pH 3.6 to 5.0, and is obviously low in fertility. Plots serve as replications in tests of ground-cover plants. Each plot is subdivided into quadrats, chiefly 6.6 by 6.6 feet or 1 milacre in size, for treatments according to factorial design.

From 1941 to 1946, tests were made on seedings or plantings of 22 grasses and leguminous cover plants.[5] Treatments, notably fertilizer, lime, and mulch, were assigned at random to quadrats in each test. Observations were taken at the end of each growing season on the development of cover in percentage of ground area measured on the central quarter of each quadrat. General indications to date from these cover-plant tests may be summarized briefly as follows: (1) Where some cover was obtained, fertilizer usually stimulated development, liming was beneficial in some cases, and mulching proved essential for all seedings. Without mulch no cover developed because the seed was washed away before it germinated. (2) Unsatisfactory cover has resulted in exploratory tests on 18 cover plants.[6] (3) Fairly good

[4]Experimental areas were made available through cooperation of the Tennessee Copper Company.

[5]Plants are specified by the common names given in Kelsey, H. P., and Dayton, W. A. Standardized Plant Names. Harrisburg, Pa.: J. Horace McFarland. Ed. 2. 1942.

[6]Cover plants which to date have failed are Italian ryegrass, Sudangrass, field brome, rye hybrid, little bluestem, yellowsedge bluestem, slender bluestem, meadow fescue, Bahiagrass of Pensacola and Wilmington strains, and a perennial lespedeza native to the basin. Those which have developed some cover but of unsatisfactory density are Bermudagrass, reed fescue, birdsfoot deervetch, crownvetch, trailing lespedeza, rush lespedeza, and kudzu.

cover has been obtained from treated seedings of switchgrass, Chinese or sericea lespedeza, and plantings of shrub lespedeza. However, none of these plants is adapted for establishing protective cover quickly on extremely exposed sites in the basin. Switchgrass seedings required 2 to 4 years to develop satisfactory cover. In treated gullies, sericea may be seeded in combination with black locust planting. On these sites shrub lespedeza is surpassed by black locust in the development of cover and would be planted only because of the value of its seed as food for wildlife. (4) Of the 22 plants tested, weeping lovegrass seedings produced the best protective cover for bare, exposed sites. Tests on the establishment of weeping lovegrass cover on such sites in the basin are detailed below.

DESIGN OF WEEPING LOVEGRASS TESTS

Seeding of weeping lovegrass was tested on the three experimental areas in plots of quadrats established by the following procedure: (1) Preparation of quadrats involved raking-off large stones and leveling major irregularities. (2) Soil treatments applied broadcast were liming with ground dolomite and fertilizer elements either in mix with neutral sand filler or separately. Elements were supplied by ammonium nitrate, 33% N; Metaphos, 60% P_2O_5; and potassium chloride, 61% K_2O. (3) Seed was broadcast. The seed used tested good in viability. Seed averaged 1,000,000 per pound in the 1940 and 1941 lots from the Soil Conservation Service, Zanesville, Ohio, and 1,300,000 per pound in the 1941 lot from TVA nursery at Norris, Tenn., and the 1944 lot from Farmville, Va. (4) Mulch of broomsedge, rye, or wheat straw was spread evenly on the quadrat and tied down by cross strings to corner stakes.

The 1942 test at Copperhill was designed as an exploratory $2\times2\times2$ factorial, with or without fertilizer, lime, and mulch. The design involved 32 quadrats in 8 incomplete blocks with the triple interaction confounded completely. Treatments added were (1) 200 or 300 pounds of 4–12–4 fertilizer per acre, and (2) 1 or 1½ tons of lime. Quadrats were seeded at 3 to 4 pounds to give about 4 million seed per acre, either in December 1941 or April 1942. The alternative values were minor variations between replications and not subject to test. Quadrats not mulched showed no cover. Averages for cover development on 16 mulched quadrats by season are presented in Table 1. A preliminary 1941 test, which involved seeding on May 1 of 16 quadrats at Isabella, was similar throughout. Due to loss occasioned by trespass damage, only one block remained, which was inadequate for reporting the 1941 test.

The 1945 test A was established at Copperhill in a 9×9 quasi-Latin square of 81 quadrats. This design[7] has proved effective for testing nitrogen, phosphorus, potassium, and lime at three levels each by error estimated from higher interactions. The main treatments supplied N at 0, 10, or 40 pounds per acre; P_2O_5 at 0, 20, or 80; K_2O at 0, 5, or 20; and limestone at 0, 1,000, or 4,000 pounds. The 81 combination treatments were assigned appropriately at random to the quadrats. Application of treatments and raking-in, seeding at 3½ pounds, and mulching at 2½ tons were completed on March 22. Initial development of cover is averaged for combinations of nitrogen and phosphorus in Table 2. Neither potassium nor lime affected average cover development appreciably. However, results for combinations of potassium and lime are given in Table 3 to show their interaction.

The 1945 test B was established in blocks at Copperhill, Isabella, and Ducktown. Each block included six whole plots mulched at 1¼, 2½, or 5 tons per acre, with or without interplanting of Virginia pine. Each plot included four subplots seeded at 3½ or 7 pounds, with or without raking-in of the 8–16–2 fertilizer, which was broadcast at 300 pounds throughout the plots. Treatment was completed on April 20. Initial development of cover is averaged for mulching and seeding rates in Table 4. The "pine" and "raking-in" factors warrant only mention in the discussion.

[7]YATES, F. Design and analysis of factorial experiments. Imperial Bur. Soil Sci. Tech. Comm. 35. 1937.

The 1946 test was established in two blocks at Copperhill and one at Isabella. Each block included six whole plots mulched at 2, 3, or 4 tons per acre and seeded at 4 or 8 pounds. On each plot, four subplots were fertilized with the combinations of N at 20 or 80 pounds, and P_2O_5 at 40 or 120 pounds. Treatment was completed on March 31. First-season development of cover for combinations of nitrogen and phosphorus, excluding quadrats mulched at the excessive 4-ton rate, is averaged in Table 2. Cover on all quadrats is averaged by mulching and seeding rates in Table 4. Auxiliary plots established in 1946 included excessive rates of seeding at 16 pounds and mulching at 6 tons. Raking-in of fertilizer and light additions of potassium and lime were included also. First-season indications from this non-orthogonal test are not reported. They merely substantiate results discussed for the 1945 and 1946 tests.

DISCUSSION OF RESULTS

Four seeding tests on weeping lovegrass provided data on density of cover. Results which appeared noteworthy following statistical analysis are summarized in Tables 1 to 4.

TABLE 1.—*Development of cover of weeping lovegrass from 1942 seeding treated with fertilizer and lime in percentage of ground area.**

Soil treatment added	Total cover at the end of growing season				
	First	Second	Third	Fourth	Fifth
None	13	23	36	49	40
Lime	11	22	36	52	52
Fertilizer	35	57	75	84	85
Fertilizer and lime	42	66	76	90	92
Min. diff. signif. at P = 5%	19	35	37	40	33

*Each value given is an average for four quadrats seeded at 3 to 4 pounds, mulched at about 1 ton. Treatment additions tested were fertilizing with 4–12–4 at 200 or 300 pounds, and liming with 1 or 1½ tons of ground dolomite.

TABLE 2.—*Initial cover of weeping lovegrass resulting from seedings fertilized with nitrogen and phosphorus at varied rates in percentage of ground area.**

Nitrogen addition in lbs. of N per acre	Phosphorus addition in lbs. of P_2O_5 per acre							
	1945 seeding A after						1946 seeding after first season	
	First season			Second season				
	0	20	80	0	20	80	40	120
0	5	9	23	1	16	44	—	—
10	13	33	52	14	59	80	—	—
20	—	—	—	—	—	—	31	40
40	16	54	77	24	73	96	—	—
80	—	—	—	—	—	—	39	47
Min. diff. signif. at P = 5%	10			18			12	

*Each value given is an average: In 1945 test A, for nine quadrats seeded at 3½ pounds and mulched at 2½ tons; in 1946 test for 12 quadrats seeded at 4 and 8 pounds and mulched at 2 and 3 tons.

TABLE 3.—*Initial cover of weeping lovegrass from 1945 seeding as affected by addition of potash and liming in percentage of ground area.**

Potassium addition in lbs. of K_2O per acre	Liming, tons of ground dolomite per acre					
	First season			Second season		
	0	½	2	0	½	2
0	34	30	27*	48	47	39*
5	32	29	32	46	43	52
20	22*	39	35	26*	54	53
Min. diff. signif. at P = 5%	10			18		

*Each value given is an average for nine quadrats in 1945 test A which were seeded at 3½ pounds, mulched at 2½ tons, and treated with nine nitrogen-phosphorus combinations (Table 2). Starred values are the lowest two average cover percentages after the first and after the second season.

TABLE 4.—*Initial cover of weeping lovegrass resulting from seeding and mulching at varied rates in percentage of ground area.**

Mulching rate, tons per acre	Seeding rate in pounds per acre					
	1945 seeding B after				1946 seeding after first season	
	First season		Second season			
	3½	7	3½	7	4	8
1¼	27	40	36	49	—	—
2	—	—	—	—	44	52
2½	41	44	41	52	—	—
3	—	—	—	—	22	38
4	—	—	—	—	26	15
5	35	39	43	51	—	—
Min. diff. signif. at P = 5%	11		14		19	

*Each value given is an average: In 1945 test B for 12 quadrats treated with 300 pounds of 8-16-2 fertilizer; in 1946 test for 12 quadrats fertilized with 20 or 80 pounds of N and 40 or 120 pounds of P_2O_5.

Lovegrass in the 1942 test (Table 1) was benefited significantly by fertilizer but not by lime. By the fifth year, response of cover to treatment averaged 42% for fertilizer and 10% for lime. The initial stand of lovegrass from mulched seedings on exposed sites improved in density up to the fifth year—especially on heavily-treated quadrats. Five years is an ample period of soil fixation for pine plantations to become established.

In the 1945 test on varied nitrogen, phosphorus, potassium, and lime, only nitrogen and phosphorus showed benefits after each season. Main effects for both elements were significant. After the second

season, improvement of cover from the addition of nitrogen at 10 pounds per acre averaged 31%; at 40 pounds, 44%. Improvement from phosphoric acid at 20 pounds averaged 36% and at 80 pounds, 60%. The interaction of nitrogen and phosphorus attains significance in the linear-linear component. Thus, in Table 2, the second season cover for neither element and the high level of both averaged 48%, compared with cover of 34%, the average for the high level of single elements. This contrast is prominent for the low level also. Intermediate and heavier additions of nitrogen and phosphorus were tested in 1946. First-season cover averaged somewhat poorer than expected and suggested diminishing returns from the heavier dressings. These tests indicate that for development of initial cover from seedings of lovegrass in the Copper Basin both nitrogen and phosphorus should be applied. Application of one element only would be inefficient.

Besides nitrogen and phosphorus in the 1945 test, the only significance found was for the potassium and lime interaction in the linear-linear components. Cover for each season was poor from the heavy dressing of potassium alone or lime alone (Table 3). The average of these is significantly worse than for neither dressing, and for heavy dressing with both potassium and lime. These tests indicate that development of inital cover of lovegrass does not require potassium or lime. Heavy dressings of one without the other would be detrimental.

Different rates of seeding and varied mulching were tested in 1945 and 1946 (Table 4). Results of these tests show little statistical significance but have practical application. Doubling the seeding rate of 3½ or 4 pounds produced only slightly denser lovegrass cover. Mulch disappears rapidly from seedings in the Copper Basin, and 1¼ tons appears a minimum rate for seedings of lovegrass. Mulching at 3 tons or more is excessive, in view of the slightly poorer cover obtained.

Additional results from lovegrass tests have not been tabulated because of nonsignificance. The raking-in of fertilizer preparatory to seeding lovegrass resulted in slightly poorer initial cover. It is a costly operation that is not justified in the Copper Basin. The interplanting of pine in lovegrass seedings showed slight benefits in the early development of both plants. For the establishment of permanent cover on bare, exposed sites in the Copper Basin it appears feasible to seed lovegrass for initial protective cover and to interplant pine.

The lovegrass cover obtained in these seeding tests was characterized by high variability. Certain quadrats—usually not fertilized—have only a few tufts of grass. Others, such as the two at Copperhill illustrated in Fig. 2, support good stands. Lovegrass cover is expected to persist and develop greater density, but not to spread beyond the area seeded. The test results serve as the basis for the following minimum recommendations for erosion-control planting practices on bare, exposed sites in the Copper Basin: Treat the site in late spring (April) by fertilizing with 15 pounds of nitrogen and 30 pounds of phosphoric acid per acre. Seed at the rate of 3 pounds, and mulch at 1½ tons, taking precautions against the shifting of straw with resultaut exposure of the new seeding. Pine may be interplanted at the time of

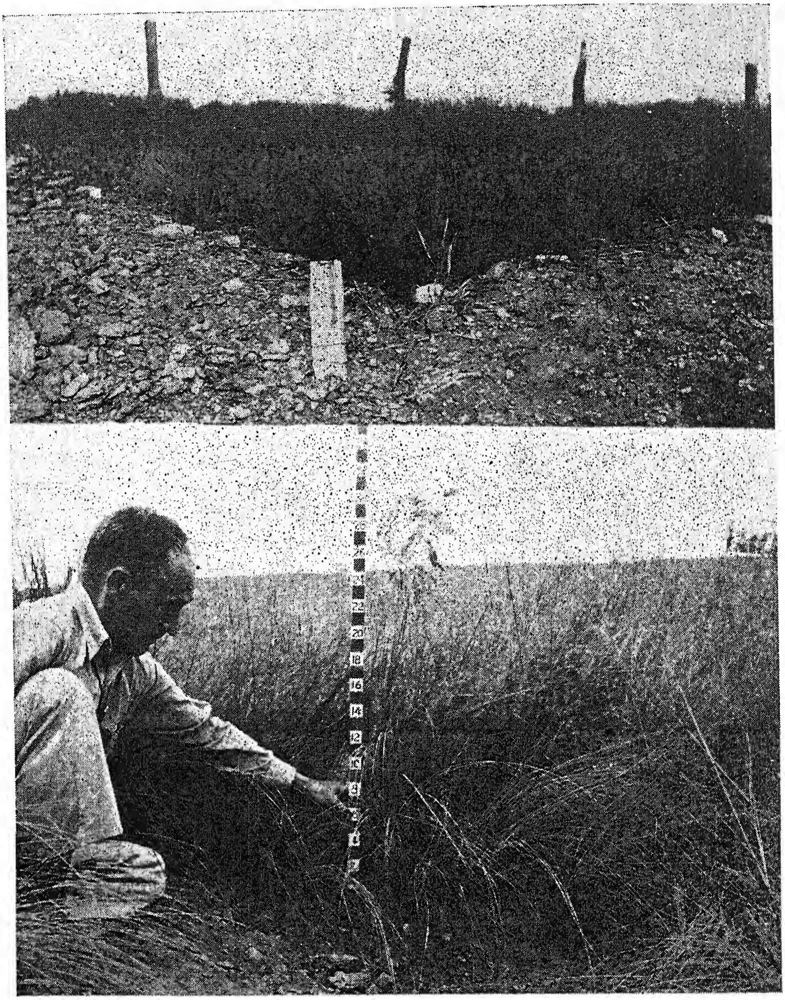

Fig. 2.—Weeping lovegrass from seedings on bare, exposed sites on Copperhill experimental area. *Above*, exceptional first-season stand with density of 90%; *below*, after 5 years the grass roots are holding 6 inches of soil from eroding.

seeding. Such treatment should effect first-season lovegrass stands of at least one-third complete cover. With exclusion of grazing and burning, protective cover should be assured for establishment of the pine plantation.

SUMMARY

Weeping lovegrass, *Eragrostis curvula*, a perennial bunch grass recently introduced from South Africa, has been tested on bare, severely eroding, adverse sites in the Copper Basin of southeastern

Tennessee. It surpassed 21 grasses and legumes in establishing cover on exposed sites of infertile strongly acid subsoil. In weeping lovegrass seeding experiments on such sites, measurements were taken on the development of cover for 1 to 6 years, and significant results of treatments are reported. Mulch proved essential to keep seedings from washing out. Fertilizer was highly beneficial. Liming was of doubtful importance.

A factorial test of four nutrients at three levels showed (1) significant benefits from nitrogen and phosphorus which were striking for combined application, and (2) detrimental effects of potassium and lime from heavy dressings of either one alone.

Seeding at 4 pounds per acre produced lovegrass cover which was improved but little by doubling the seeding rate.

Mulch applied for protection of seedings disappears rapidly in the basin, but mulching rates of 3 tons or more appeared excessive for the development of lovegrass cover.

Results of tests indicate that weeping lovegrass cover can be obtained from seedings on bare, exposed sites in the Copper Basin. Since 100% initial stands are improbable, it may be sought to obtain first-season stands of at least one-third complete cover, which should increase in density. With elimination of grazing and burning this should provide ample site protection for a 5-year establishment period for pine plantations.

Minimum recommendations are given for treatment late in the spring. These include fertilizing with 15 pounds of nitrogen and 30 pounds of phosphoric acid per acre, seeding at 3 pounds per acre, and mulching at 1½ tons per acre with precautions against shifting of straw and resultant exposure of the new lovegrass seeding.

Killing Weed Seeds in the Grass Seedbed By the Use of Fertilizers and Chemicals[1]

J. A. DEFRANCE, R. S. BELL, AND T. E. ODLAND[2]

THE removal of weeds from seedbeds, newly planted turf, gardens, and field crops, whether by hand or by cultivation, requires time and expense. Various chemicals and fertilizers have been applied to soils contaminated with weed seeds in a series of studies carried on for several years in the greenhouse and field at the Rhode Island Agricultural Experiment Station. Results of these experiments indicate the practical use of such chemicals and fertilizers for killing weed seeds in soils prior to planting turf or other crops.

Materials are available which will destroy weed seeds in the seedbed, leave little or no toxic residue for future plantings, and at the same time add fertility to the soil, thus saving much time and money involved in weeding and maintenance.

REVIEW OF LITERATURE

Abbott (1)[3] reported that "Aero" Cyanamid, applied in the fall at the rate of 1 pound per square yard and worked into the soil to a depth of 5 inches, effectively prevented germination of weed seeds in tobacco plant beds.

Welton and Carroll (7) stated that applications of Cyanamid at the rate of 20 pounds per 1,000 square feet and worked into the surface soil gave fairly satisfactory control of many of the more common weeds, such as the chickweeds, shepherd's purse, milk purslane, dandelion, and others. For the plantains and many of the annuals, like foxtail and crabgrass, however, 40 pounds per 1,000 square feet did not give complete control, although most of the seeds were killed.

DeFrance (4) reported the successful use of organic and inorganic nitrogenous fertilizers for destroying weed seed in compost, and suggested that the method was practical and economical from the greenkeeper's standpoint because both sterilized compost and fertilizer could be applied as topdressing in one operation.

Carr (3) reported that the weed population in tobacco beds was reduced 87% with 1 pound of Cyanamid per square yard, and that a 60- to 90-day period should elapse after treatment before it is safe to seed. A superior growth and stand of tobacco plants was obtained on treated soil.

An anonymous (2) mimeographed paper from the Georgia Coastal Plain Experiment Station states, "Treatment of plant bed soil with a combination of Uramon (urea) and Cyanamid (calcium cyanamide) 60 to 90 days before seeding eliminates 70 to 95% of weed growth, partially controls root knot, and insures superior growth and stands of tobacco plants. Either chemical may be used alone, but a combination of the two is more effective than either used separately and 100 pounds of Uramon plus 50 pounds of Cyanamid is suggested for each 100 square yards. If Cyanamid is used alone, 100 pounds of this will be necessary."

For treating tobacco beds, Henderson, Matthews, and Jenkins (6) suggested the use of 1 pound of either Uramon or calcium cyanamide or a combination of 1 pound of Uramon and ½ pound of calcium cyanamide per square yard of plant bed area, and stated that the treatment would not give complete control of weeds, but

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[3]Figures in parenthesis refer to "Literature Cited", p. 535.

would reduce the number of weeds to such an extent that with a little hand weeding an excellent crop of plants could be grown on soil infested with weed seeds.

Hammer, Moulton, and Tukey (5) conducted successful studies on treatment of muck and manure with 2,4-dichlorophenoxyacetic acid in solution to inhibit germination of weed seed, and suggested this treatment as a method of controlling weed seed in muck and manure where these materials were used in topdressings of lawns and golf courses.

MATERIALS AND METHODS

Chemicals and fertilizers used in the tests reported here for treating soil contaminated with weed seeds were as follows: Acrylon, allyl alcohol, ammonium nitrate, ammonium sulfamate, ammonium sulfate, ammonium thiocyanate, Biuret, Granular "Aero" Cyanamid, dimethylourea, limestone, Milorganite, Milarsenite, sodium nitrite, sodium nitrate, Uramon, and 2,4-dichlorophenoxyacetic acid, including the ammonium, calcium, potassium, and sodium salts, and the butyl ester of 2,4-D. Rates of application reported in this paper are on the basis of 1,000 square feet.

One-eighth pound of white clover, ¼ pound Rhode Island Colonial bent or ¼ pound redtop, and 1 pound weed seed obtained from a bent grass cleaning process were thoroughly mixed with the upper 3 inches of the weedy field soil a few days before the treatments were applied.

The chemicals and fertilizers were applied dry or in solution and were worked into the soil either with a rake or a hand wheel-cultivator. In some cases the treated soils were watered to maintain adequate moisture. Grasses and other crops such as alfalfa, radishes, and seedlings of cabbage and tomato were planted at weekly or monthly intervals in the treated soils in order to determine the time required for the dissipation of toxic material. Observations were made on the germination and growth of weeds and crops. In some cases green weight of crops was recorded.

Several tests were conducted in the greenhouse and in the field to determine (a) the concentration of the materials which would effectively prevent germination of the weed seeds in the soil; (b) how soon after the application of the materials grasses and other crops could be safely seeded or transplanted; and (c) the influence of the materials on the pH, NH_3-nitrogen, NO_3-nitrogen, and conductivity of the soil.

RESULTS

In the greenhouse, during the winter of 1942–43, practically complete inhibition of germination and growth of weed seeds was obtained with the following: Ammonium sulfate, 185 pounds per 1,000 square feet; Cyanamid, 90 pounds; and Milorganite, 1,235 pounds. Comparable concentration of the materials gave similar control regardless of cultivation into the soil 3 or 6 inches deep. This preliminary test indicated that fertilizers might be of value for weed control in seedbed preparation for new lawns, vegetable and other field crop areas, and also might enrich the soil in nitrogen.

During the winters of 1943–44 and 1944–45, ryegrass, alfalfa, and seedlings of cabbage and tomato were planted in soils in the greenhouse to test the residual toxicity 1 or 2 months after treatment with various amounts of ammonium thiocyanate, ammonium sulfate, Biuret, Cyanamid, and Uramon to destroy the weed seeds. Results of these tests indicated that the materials, used in sufficient quantity, destroyed weed seeds in the soil and after a few weeks' time the toxic principle of the material disappeared, probably due to decomposition and leaching, so that grass and other crops could be planted.

Field tests during the summers of 1944 and 1945 indicated that ammonium thiocyanate and ammonium sulfamate were effective in

such relatively low quantities as 3 pounds; rates from 50 to 100 pounds were needed to get good control of weeds with nitrogenous fertilizers such as ammonium nitrate, ammonium sulfate, sodium nitrate, Cyanamid, and Uramon; weeds were not inhibited by 10 pounds of dimethylourea, sodium nitrite, or Acrylon, or 75 pounds of Milarsenite.

Ammonium, sodium, and ester compounds of 2,4-D at 1/8 and ½ pound prevented germination or growth of many weeds. The addition of ammonium sulfamate, thiocyanate, or thiourea at rates of 1 or 2 pounds did not increase the effectiveness of the 2,4-D significantly but increased residual toxicity in the treated areas.

The use of 20 pounds of ammonium nitrate, sodium nitrate, Uramon, or limestone with ammonium thiocyanate appeared to decrease the effectiveness as a weed control material and also reduced the residual toxicity.

Plantings of ryegrass indicated that a definite period of time must elapse after treatment before a crop can be planted safely.

The results of tests in the greenhouse during 1946 are given in Table 1. All materials used for soil treatment gave very good inhibition of clover, grass, and weeds and, in general, after a few weeks did not leave toxic residue sufficient to hinder growth of ryegrass and redtop.

Ammonium sulfamate at 2 and 3 pounds inhibited nearly all weeds in flats; plantings of ryegrass 2, 4, and 6 weeks after treatment were satisfactory, but a lapse of 6 weeks after treatment appeared necessary for good germination and growth of redtop where 3 pounds of this chemical were used.

Ammonium thiocyanate at the 3-pound rate also inhibited nearly all weeds and appeared to need a lapse of 4 weeks after treatment for satisfactory ryegrass and 6 weeks for redtop to grow. Biuret at 3 and 5 pounds gave good control of weeds, but the soil needed more than 6 weeks to lose toxicity so that ryegrass and redtop could be grown. Twenty-five pounds of sodium nitrite were needed to kill all weed seeds and good growth of ryegrass and redtop resulted when planted at intervals of 2, 4, or 6 weeks after treatment.

Cyanamid at 50 pounds gave control of weeds in the flats and good growth of ryegrass was obtained from plantings at the end of 4 weeks; good growth of redtop resulted at the end of 6 weeks. Uramon also gave control of weeds at the 50-pound rate in flats.

Ammonium, calcium, potassium, and sodium salts of 2,4-D gave fairly satisfactory inhibition of weeds in the flats. Plantings of ryegrass 2, 4, and 6 weeks after treatment were satisfactory, but, in general, redtop required more time in comparison for satisfactory germination and growth.

The materials used and the results of field tests in 1946 are presented in Table 2. After the treatments were applied to plots 10 x 10 feet, plantings of radishes, perennial ryegrass, and Colonial bent were made at intervals of 2,4, 6, 8, and 11 weeks in rows across the plots. All the chemicals, fertilizers, and combinations at the rates used, except Acrylon and Biuret, gave good control of weeds.

Eight weeks after treatment no weeds had appeared where the fol-

TABLE 1.—*Weed control in seedbed greenhouse test, 1946.*

Material	Lbs. applied per 1,000 sq. ft.	Growth response, number weeks after treatment						Percentage weeds and grass in treated soil 1 month after treatment	
		Ryegrass			Redtop				
		2	4	6	2	4	6	Weeds	Grass
Ammonium sulfamate..	1	E*	E	E	G	G	E	10	40
Ammonium sulfamate..	2	G	E	E	G	O	E	Trace†	Trace
Ammonium sulfamate..	3	G	E	E	F	P	O	0	Trace
Ammonium thiocyanate	2	F	E	E	O	F	E	1	5
Ammonium thiocyanate	3	P	G	E	P	O	E	1	4
Biuret................	3	O	F	P	O	O	G	Trace	1
Biuret................	5	P	F	F	O	P	F	Trace	Trace
Sodium nitrite.........	15	G	G	G	G	F	E	2	3
Sodium nitrite.........	25	G	E	G	G	F	G	0	1
Ammonium nitrate.....	50	F	G	F	G	F	F	0	3
Ammonium mitrate....	75	F	F	G	O	O	G	0	3
Cyanamid...........	50	P	G	E	P	P	E	0	0
Cyanamid...........	75	P	G	F	P	P	F	0	0
Uramon	50	G	G	F	G	G	F	0	0
Uramon.............	75	G	G	G	F	P	P	0	Trace
2,4-D ammonium......	⅛	G	E	E	P	P	E	3	2
2,4-D ammonium......	¼	F	E	E	P	O	E	Trace	2
2,4-D calcium.........	⅛	E	E	E	F	F	E	3	2
2,4-D calcium.........	¼	G	E	E	G	F	O	2	2
2,4-D potassium.......	⅛	G	E	E	P	G	G	6	3
2,4-D potassium.......	¼	E	E	E	P	P	P	1	2
2,4-D sodium..........	⅛	G	E	E	P	P	P	2	2
2,4-D sodium..........	¼	G	E	E	F	P	O	2	2
Check................	None	E	E	E	E	E	E	100	100

*Growth response of crops planted after treatment. E=Excellent; G=Good; F=Fair; and P=Poor.
†Less than 1%.

lowing were used: Cyanamid, 75 pounds plus 1/8 pound of sodium salt of 2,4-D; ¼ pound of sodium 2,4-D; ½ pound of 2,4-D ester; 4 and 6 pounds ammonium thiocyanate; 125 pounds Cyanamid; 75 and 100 pounds Uramon; 100 pounds of ammonium nitrate, ammonium sulfate, or sodium nitrate.

Individual plantings of perennial ryegrass and Colonial bent, made as soon as 2 and 4 weeks after treatment, responded with satisfactory germination and growth in soils where many of the treatments had been applied and excellent control of weeds had been obtained.

Cyanamid at 75 pounds per 1,000 square feet was one of the treatments which appeared to give promise of inhibiting weeds in the turf seedbed without leaving a toxic residue for too long a time and of adding fertility to the soil. Very little difference in degree of weed control occurred from the two methods of application of Cyanamid. Both cultivating and a combination of cultivating and raking gave very good control.

The 2,4-D materials gave good control of weeds and, in general, appeared to have a longer toxic duration for bent grass than for rye-

TABLE 2.—*Weed control in seedbed field test, 1946.*

Plot No.	Material	Lbs. applied per 1,000 sq. ft.	Number of weeks after treatment before satisfactory plantings were obtained			Weed content after treatment	
			Scarlet Globe radish	Perennial ryegrass	Colonial bent	2 weeks	8 weeks, %
1	Cyanamid + ammonium sulfamate	75 2	6	4	4	None	6
2	Cyanamid + ammonium thiocyanate	75 2	6	4	4	None	3
3	Cyanamid + 2,4-D sodium	75 1/8	6	4	4	None	0
4	2,4-D sodium	1/8	6	4	4	Many†	3
5	2,4-D sodium	1/4	6	2	4	Many	0
6	2,4-D sodium	1/2	6	2	6	Trace	1
7	2,4-D ester	1/8	2	2	2	Many	23
8	2,4-D ester	1/4	6	2	4	None	1
9	2,4-D ester	1/2	8	4	4	None	0
10	Check	None	—	—	—	Many	100
11	2,4-D ammonium	1/8	8	2	4	Trace	2
12	2,4-D ammonium	1/4	8	2	4	Trace	1
13	2,4-D ammonium	1/2	8	2	4	None	T
14	Ammonium thiocyanate	2	6	2	2	None	7
15	Ammonium thiocyanate	4	6	4	2	None	0
16	Ammonium thiocyanate	6	8	T	2	None	0
17	Ammonium sulfamate	2	6	T	2	Trace	15
18	Ammonium sulfamate	4	6	T	2	Trace	6
19	Ammonium sulfamate	6	T*	T	4	None	6
20	Alcohol, allyl	2	6	T	2	None	8
21	Alcohol, allyl	4	6	2	2	None	9
22	Alcohol, allyl	6	6	4	2	None	3
23	Sodium nitrite	20	6	2	2	None	4
24	Sodium nitrite	30	11	4	2	None	T
25	Cyanamid, cultivated	50	2	2	2	None	3
26	Cyanamid, cultivated	75	6	4	2	None	2
27	Cyanamid, cultivated	100	6	4	2	None	1
28	Cyanamid C50, R25‡	75	6	2	2	None	4
29	Cyanamid C75, R25	100	6	4	4	None	1
30	Cyanamid C100, R25	125	6	4	2	None	0
31	Biuret	3	6	2	2	Few	28
32	Check	None	—	—	—	Many	100
33	Biuret	4	6	T	2	Many	29
34	Biuret	5	6	4	4	Many	8
35	Uramon	50	6	2	2	Few	8
36	Uramon	75	T	T	T	None	0
37	Uramon	100	T	T	T	None	0
38	Ammonium nitrate	100	T	T	2	None	0
39	Ammonium sulfate	100	T	T	2	None	0
40	Sodium nitrate	100	6	6	2	None	0
41	Acrylon	10	6	T	2	Many	45
42	Acrylon	20	2	2	2	Many	86

*T = Still toxic at end of 11 weeks after treatment.
†Many germinated but died shortly thereafter.
‡C = Cultivated in; R = Raked into soil.

grass, whereas with the other chemicals and fertilizer bent grass appeared more tolerant than ryegrass. Radishes appeared to be more affected by the residual toxicity than either ryegrass or bent grass.

Tests were made also on five new putting greens at two nearby golf courses. Treatments with Cyanamid at 50 and 75 pounds per 1,000 square feet were used and it was estimated that 75% to 95% control of undesirable grasses and other weeds was obtained. When the treated soil was seeded with velvet bent 6 to 8 weeks after treatment, satisfactory growth occurred.

SUMMARY AND CONCLUSIONS

A series of experiments in the greenhouse and field showed that several fertilizers and chemicals inhibited weed growth either by killing the seeds or by killing seedlings shortly after germination. The materials were applied dry or as spray solutions and thoroughly mixed by cultivation or raking into the upper 2 or 3 inches of soil.

The period of time after treatment before grass, radishes, alfalfa, or seedlings of tomato, cabbage, or other crops could be planted safely varied with the different materials and the amounts applied.

Treatments of certain fertilizers or chemicals applied in the spring or summer should be very practical for providing weed-free seedbeds for permanent planting of turf in early September; likewise, treatments in the fall should prepare weed-free seedbeds for planting the following spring. Increase in moisture seemed to be beneficial in decreasing the toxic residue of the materials.

Sterilizing soils with fertilizers or chemicals appears to be a very practical method of controlling weeds and fertilizing seedbeds in one operation. This is especially true of fertilizers which do not appreciably alter the soil complex and which do not leave residual toxicity for long periods.

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Two Types of Late Spring Frost Injury to Winter Wheat[1]

J. E. LIVINGSTON AND J. C. SWINBANK[2]

THE late frost that occurred on May 10 and 11, 1946, offered an excellent opportunity to observe two distinct types of frost injury to hard red winter wheat. An early spring had stimulated the development of the wheat plants in all counties east of the Panhandle so that they were heading from 3 to 4 weeks earlier than normal. Heads of the early varieties, Triumph, Wichita, Comanche, and Pawnee, were beginning to emerge from the boot. Injury to the plants in this stage of development was primarily to the heads, many becoming partially or completely sterile as a result. Wheat in the Panhandle counties, on the other hand, was growing more or less normally so that the plants were from 8 to 10 inches in height. The heads were in an early stage of development, well protected by the sheath and also by a thin layer of snow. There was only a small amount of injury to the heads of these plants, although there was considerable injury to the stems.

In view of the two distinct types of injury, the first portion of this paper is devoted to a discussion of the head injury and the second portion to the stem injury.

Ten varieties of hard red winter wheat had been planted in replicated yield test plots in 11 counties scattered throughout the southern half of Nebraska. These same varieties were planted also in nonreplicated demonstration plots in Polk, Adams, and Harlan counties. Counties in which the yield plots were located, minimum temperature reached, and the approximate duration of the sub-freezing temperature are shown in Fig. 1. Detailed temperature records for three locations in the affected areas are listed in Table 1.

HEAD INJURY

Injury to the heads showed as sterile florets. Anthers in the early varieties were ready, and in some cases, starting to dehisce. Heads in this condition were apparently more susceptible to frost injury than later heads. The injury was very similar to that described by Suneson (2)[3] who artificially emasculated wheat heads with frost treatments. He found that temperatures from 27° to 30° F for 15 to 24 hours caused injury to all floral structures when the florets had emerged from the leaf sheath but were not yet fertilized. Partial injury to the heads occurred when exposed to temperatures ranging from 27° to 36°

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[3]Figures in parenthesis refer to "Literature Cited", p. 544.

TABLE 1.—*Hourly air temperatures in Cheyenne, Phelps, Hall, and Dawson counties, Nebraska, 1946.*

Time	Temperature			
	Cheyenne County	Phelps County	Hall County	Dawson County
		May 9		
10:30 p.m.	32.1	—	—	—
		May 10		
12:30 a.m.	31.5	46	51	50
2:30	30.8	38	45	40
4:30	29.1	36	43	38
6:30	29.1	34	39	37
8:30	29.0	32	32	32
10:30	30.3	31	33	32
12:30 p.m.	30.3	31	33	33
2:30	28.8	34	35	35
4:30	31.3	35	35	36
6:30	31.9	36	37	37
8:30	29.3	34	36	33
10:30	26.9	31	35	31
		May 11		
12:30 a.m.	26.5	30	34	28
2:30	25.1	28	30	27
4:30	23.0	28	28	25
5:30	24.2	30	27	24
6:30	28.5	35	29	28
7:30	34.0	42	35	33
8:30	38.3	46	40	40
10:30	47.7	50	48	50
12:30 p.m.	53.0	55	53	53
2:30	56.8	59	58	58
4:30	56.8	63	58	60
6:30	51.9	59	60	59
8:30	39.5	49	54	51
10:30	33.6	45	46	45
		May 12		
12:30 a.m.	33.0	42	42	37
2:30	31.9	—	36	33
4:30	31.5	—	36	30
6:30	40.5	—	35	30
8:30	57.0	—	43	45

F for 15 to 24 hours while the heads were still protected by the leaf sheath. In this case the anthers were sterile but the pistillate parts were still functional.

The injury to the wheat heads reported here was primarily the partial-injury type. All degrees of head sterility were present, as shown in Table 2 and Fig. 2.

Florets at the tip of the head were most frequently injured and the basal florets least frequently. This may be related to the degree of emergence of the head from the sheath or to the development of the pollen. The fact that the basal or middle florets were sometimes in-

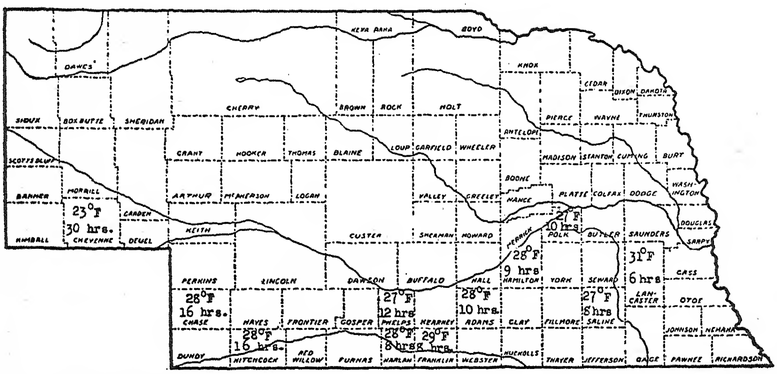

FIG. 1.—Minimum air temperature and approximate duration of subfreezing temperatures on May 10 and 11, 1946.

TABLE 2.—*Percentage of heads showing partial and total sterility resulting from frost injury May 10 and 11, 1946, from records taken June 24–29, 1946.*

Variety	Number of tests	Percentage heads injured*				
		Base	Midsection	Tip	Combination	Entire head†
Wichita...	12	4.0	3.9	10.1	13.6	13.7
Comanche	11	3.0	3.3	4.6	4.2	5.3
Pawnee...	14	1.7	3.9	10.3	3.9	2.2
Nebred...	14	1.7	1.3	10.4	1.3	1.3
Cheyenne	14	0.5	1.1	3.6	0.8	0.5
Turkey...	10	1.7	3.0	8.5	1.1	1.1
Tenmarq..	12	1.8	2.1	5.6	2.7	1.9
C. I. 12142	7	1.1	2.6	7.9	1.5	1.2
C. I. 11972	7	0.8	3.2	5.8	2.2	1.0
Triumph..	8	4.2	3.1	8.6	10.2	7.7
Blackhull	5	2.4	4.0	6.9	2.0	2.7
Average...		1.1	2.9	7.5	3.9	3.5

*Heads with less than one-third of the florets sterile are listed in the columns headed "Base", "Midsection", or "Tip" according to the region injured. Heads with from one-third to two-thirds of the florets sterile are listed in the column headed "Combination" as more than one region of the head was involved.

†Includes heads with from two-thirds to all the florets sterile.

jured while the rest of the head set seed normally indicated that the condition of the pollen was important along with the exposure of the head. Stout and Johnson (1) express the opinion that the florets "just in bloom" were the most susceptible to injury. They give a good description of the types of head injury.

The amount of floral sterility in the various varieties is given in Table 3.

These figures are an estimated percentage of the sterile florets per variety at a given location. They were obtained by counting 100 heads in each of three replications and by recording the number of heads with sterile florets and the portion of the head thus affected.

TABLE 3.—*Estimated percentage of sterile florets resulting from freezing injury on May 10 and 11, 1946, in replicated yield test plots of winter wheat.*

County	Variety									
	Wichita	Comanche	Pawnee	Nebred	Cheyenne	Turkey	Tenmarq	C. I. 12142	C. I. 11972	Triumph
Lancaster	30.0	0.2	1.2	15.6	2.6	1.0	2.4	—	—	—
Saline	1.2	0.0	1.4	0.6	0.1	2.2	0.4	1.7	0.0	2.8
Polk	44.1	19.2	11.1	1.2	0.0	1.3	5.3	1.5	2.8	60.2
Polk (d)*	—	—	4.5	0.5	3.0	—	3.2	—	—	—
Hamilton	22.0	—	1.2	0.8	0.0	—	—	—	—	31.0
Adams	9.5	7.7	9.0	2.6	0.9	2.7	3.5	1.5	0.9	6.5
Adams (d)*	—	6.1	6.7	6.9	4.8	5.3	5.0	—	—	—
Phelps	90.8	49.5	18.8	9.1	1.4	—	17.5	—	—	—
Franklin	25.4	—	16.7	5.8	2.2	—	—	—	—	—
Harlan	15.7	6.0	4.0	9.0	3.7	6.0	4.5	7.0	10.0	6.7
Harlan (d)*	—	1.8	3.6	7.3	2.1	7.2	1.2	—	—	—
Hitchcock	22.0	11.5	25.5	9.8	7.0	13.0	12.7	15.4	10.0	19.7
Chase	13.7	2.7	3.2	8.7	3.0	6.2	7.5	5.0	3.0	19.3
Cheyenne	1.5	0.3	2.5	0.4	0.2	0.6	0.6	0.4	0.6	0.1
Average	16.0	9.5	7.8	5.6	2.2	4.5	5.3	4.7	3.9	18.5

*(d) = Demonstration plot.

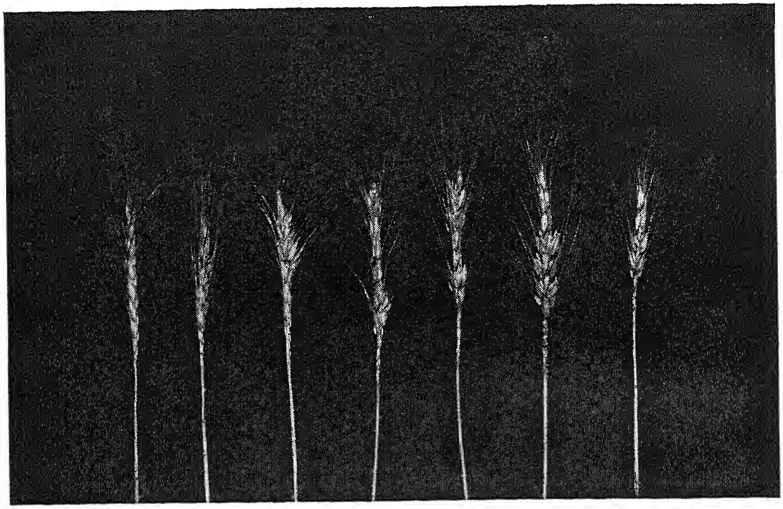

FIG. 2.—Types of head injury resulting from the late spring frost of May 10 and 11, 1946.

The stage of development of the variety was the most important factor in determining the amount of sterility produced under the prevailing conditions. Early varieties were the most severely injured. Evidence of increased injury to early varieties was observed also by Timmons and Clapp (3) in 1931. However, the observations reported here indicated that the stage of plant development was more important than any differences in variety susceptibility. For example, the variety Wichita shows 1.2% of the florets sterile in Saline County and 90.8% in Phelps county. The minimum temperature and the duration of the sub-freezing temperature were similar in the two counties. Even more significant is the comparison of this variety in Adams and Phelps counties where the fields were only 70 miles apart and the exposure to frost nearly identical.

There was also a difference in the amount of sterility when a given variety was planted in two plots in the same county. The county variety demonstration plot was usually slightly later in maturity than the variety yield test plot, even though the two plots were planted the same day within 50 feet of each other. In Polk and Adams counties the sterility of the Pawnee variety was greater in the yield test plots than in the demonstration plantings. With the Nebred variety there was very little difference in the two plots in Polk County. However, in Adams County, Nebred showed more injury in the demonstration plot than in the yield test.

In view of these results it is difficult to compare the susceptibility of the varieties. The earlier varieties, Truimph, Wichita, Comanche, and Pawnee, were injured most severely, but there was no opportunity to compare these or other varieties in the same stage of heading. Suneson (2) found a difference in the tolerance of chilling of

Ceres and Marquis spring wheat; thus it is possible that some of the differences in injury shown by the varieties in Table 3 is due to varietal differences in susceptibility.

In three instances the heads were produced at two levels. The short heads were completely sterile, while the tall heads were either normal or showed only partial sterility. This occurred with the Wichita variety in Franklin and Hamilton counties and with the Pawnee variety in Polk County. Stems bearing sterile heads apparently ceased growth and the later tillers produced the fertile heads. In other instances, mixtures of early and late maturing heads were observed, all at the same height level. The late heads always appeared to be uninjured.

STEM INJURY

The injury in Cheyenne County was quite different from that in the other counties. Temperature was lower and the duration of the sub-freezing temperature was much longer than in the other counties, as shown in Table 1. The wheat was much later and the heads were in an early stage of development, with the result that only a small percentage of the florets failed to set seed. The percentage of sterile florets was not over 0.6, except in Pawnee and Wichita, where it was 2.5 and 1.5, respectively. Most of the resulting sterile florets were at the tip of the head with a few in the mid-section.

The more serious type of injury was to the stems at the base of the plant, as shown in Fig. 3. All degrees of stem injury were found, but the most serious was either (a) bending of the stem at the lowest joint forming an elbow, (b) twisting of the stem near the base followed usually by breaking and rotting, or (c) splitting of the stem near the base followed usually by rotting. Bent stems resumed an upright position and produced grain. Twisted and split stems either rotted or continued growth. If growth was continued, many of the stems lodged because of the added weight of the grain as the heads began to fill.

Records were not taken on the percentage of each type of injury at the time of the freeze; however, records were made on the number of injured stems at harvest time and an effort was made to classify the types of injury. The results are presented in Table 4. Bent and kinked stems are included in the column headed "Injured but not rotted."

There was a great variation among varieties in the number of plants lodged as a result of stem injury. This loss was due almost entirely to the breaking of twisted or split stems. Only a very small percentage of the bent stems lodged. A high percentage of the wheat planted in Cheyenne County was of the Cheyenne variety which has an especially strong straw, thus the estimated loss in grain yield due to lodging was only about 3% for the county. However, there was considerable variation from field to field. The variability of the injury from the freeze was characteristic in all counties.

In addition to the direct loss of yield from lodging, there was undoubtedly some reduction in yield of plants where the stems were injured but not broken or rotted. Waldron (4) studied spring frost injury to Hard Federation wheat plants and found that in five out of

TABLE 4.—*Stem injury to hard red winter wheat in Cheyenne County caused by the late spring frost of May 10 and 11, 1946.*

Variety	Total stems			Twisted or broken stems			Split stems			Rotted stems*	
	Injured but not rotted, %†	Rotted, %	Lodged, %	Total, %	Rotted, %	Lodged, %	Total, %	Rotted, %	Lodged, %	Total, %	Lodged, %
Wichita	41.0	30.0	28.0	18.0	4.0	3.0	5.0	—	2.0	26.0	23.0
Comanche	45.0	29.0	29.0	—	—	—	—	—	—	29.0	29.0
Pawnee	11.0	2.0	1.0	3.0	—	—	2.0	—	—	2.0	1.0
Nebred	31.0	9.0	10.0	3.0	1.0	1.0	5.0	—	1.0	8.0	8.0
Cheyenne	18.0	3.0	3.0	2.0	—	—	1.0	—	—	3.0	3.0
Turkey	34.0	22.0	20.0	7.0	—	1.0	7.0	—	1.0	22.0	18.0
Tenmarq	24.0	10.0	8.0	4.0	2.0	2.0	18.0	5.0	4.0	3.0	2.0
Triumph	18.0	14.0	14.0	—	—	—	2.0	1.0	1.0	13.0	13.0

*No evident split or break.
†Bent, broken, and split stems.

seven cases the weight of 1,000 kernels was less on frosted than on uninjured plants. In view of these results it is probable that there was some loss in weight of grain per head in the Cheyenne County test. As can be seen in Fig. 3. many stems showed discoloration near the

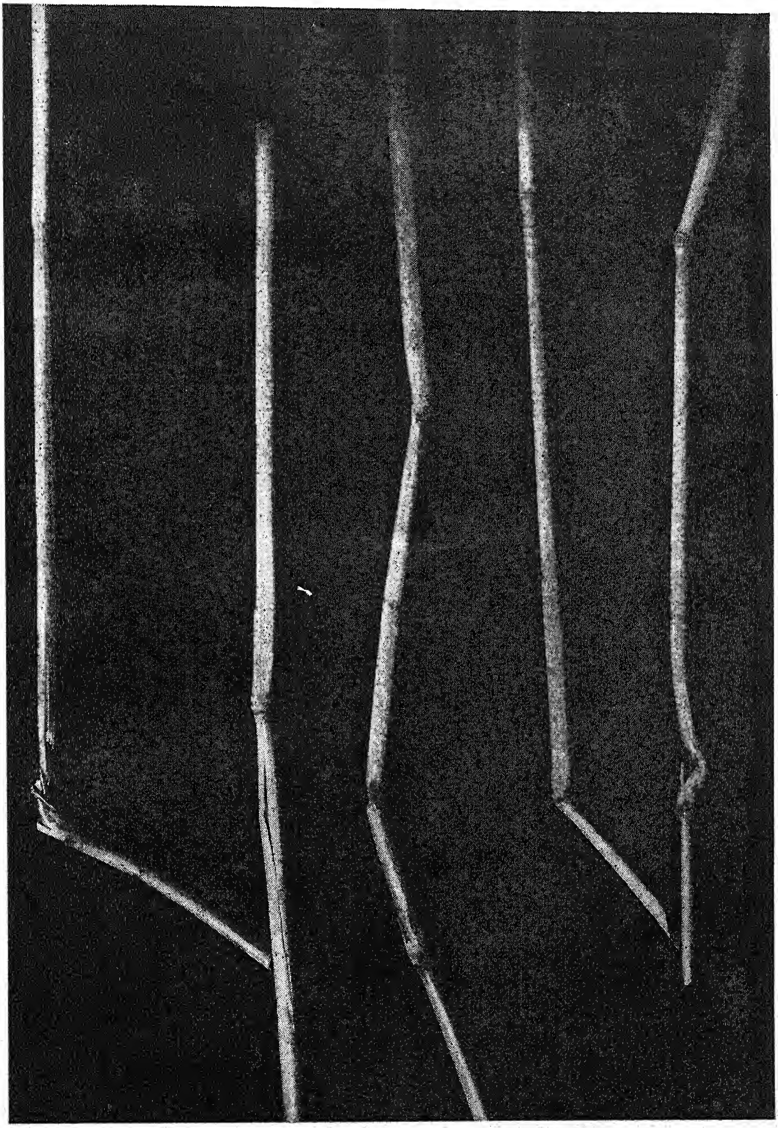

FIG. 3.—Types of stem injury caused by the late spring frost of May 10 and 11, 1946.

lower node. However, no attempt was made to determine the effect, if any, of this injury on yield.

SUMMARY

Uniform outstate hard red winter wheat nurseries, planted with 11 varieties, were subjected to a late spring freeze just as the more advanced varieties were reaching the heading stage. In 10 of the 11 counties where tests were located, varying degrees of injury resulted. Partial head sterility occurred in all varieties but was most severe in those nearest pollination. Florets at the tip of the head were injured most frequently. Stage of development of the varieties was much more important than the susceptibility of the varieties to frost.

In Cheyenne County, where the wheat was much later in development, there was only a small amount of sterility. However, there was considerable injury to the stems. All degrees of stem injury could be found, ranging from an elbow-like bend at the lower nodes to split internodes. Rots developed in many of these stems with split or broken internodes. Such stems usually lodged so that the grain, if any had developed, was lost.

Fortunately, most of the acreage in central and western Nebraska was planted to the later maturing varieties such as Cheyenne, Turkey, Tenmarq, and Nebred, and the overall loss from the freeze in the counties affected was estimated at about 3%.

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1. STOUT, H. L., and JOHNSON, A. G. Frost injury to wheat heads. Plant Disease Reporter, 30:370. 1946.
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Note

A MODIFICATION OF THE FORMULAE FOR REGRESSION

THE writer recently had occasion to determine the regression coefficient of a large number of observations grouped into frequencies where the class interval of the X observations was different from the class interval of the Y observations. No formulae for the solution of this problem could be found in the various references on statistical methods. Therefore, it was necessary to modify the formulae $by.x = \frac{Sx.y}{S\ x^2}$ to meet the situation at hand.

The method which follows is not presented as a fundamental in statistical theory but is merely offered as an assistance to those who, like the writer, have had limited training in statistics or who lack the time or inclination to work out algebraically the adaptation given.

Methods have been presented to determine the regression coefficient from the correlation coefficient but additional computation is involved in such a procedure. With this method class intervals offer no problem. Other methods are given where the regression coefficient may be calculated directly from a cross frequency chart where the class intervals of X and Y are the same. However, it is not always convenient or possible to make the intervals equal.

Owing to the differences in symbols used in various texts on statistical methods, the procedure involved in this modification is presented in detail.

A conventional cross frequency chart is set up as shown in Fig. 1. Similar charts are presented by Love[1] and Paterson[2].

Intervals of Y	Intervals of X				f_y	d_y	fd_y	fd_y^2	$S(f_y.d_x)$	$S(f_y.d_x).d_y$
							$S\ fd_y$	$S\ fd_y^2$		* Products Sum
f_x					Sf					
d_x										
fd_x					$S\ fd_x$					
fd_x^2					$S\ fd_x^2$					

* $S[S(f_y.d_x).d_y]$

FIG. 1.

[1]LOVE, H. H. The Application of Statistical Methods to Agricultural Research. Shanghai: Commercial Press, Ltd. 1937.

[2]PATERSON, D. D. Statistical Technique in Agricultural Research. New York: McGraw Hill Book Co. 1939.

In the calculation of the regression coefficient from the chart, the deviations (d) are obtained from an assumed mean by the unit step method. Corrections are therefore necessary to obtain the true sum of the deviations, the true sum of the products, and the true sums of squares.

The sum of the products is obtained from the summation of the last column in Fig. 1 together with the appropriate corrections. By substitution then, the sum of the products becomes:

$$S.P. = \left(S[S(f_y.d_x).d_y] - \frac{Sfd_x.Sfd_y}{n} \right) \times C.I._x.C.I._y$$

in which case f_y refers to the y frequencies as they occur under the several intervals of x.

The summation of x^2 by the same method is:

$$Sx^2 = \left[Sfd_x^2 - \frac{(Sfd_x)^2}{n} \right] \times C.I._x^2$$

Substituting the above values in the formulae $b = \frac{S_{x \cdot y}}{S_x^2}$ and cancelling:

$$b = \frac{\left(S[S(f_y.d_x).d_y] - \frac{Sfd_x.Sfd_y}{n} \right) \times C.I._y}{\left[Sfd^2_x - \frac{(Sfd_x)^2}{n} \right] \times C.I._x}$$

The standard deviation of y on x (S.D.x.y.) may be obtained in a similar manner. It is derived as follows:

$$S.D.y.x. = C.I._y. \sqrt{\frac{Sfd^2_y - \frac{(Sfd_y)^2}{n} - \frac{\left(S[S(f_y.d_x)d_y] - \frac{Sfd_x.Sfd_y}{n} \right)^2}{Sfd^2_x - \frac{(Sfd_x)^2}{n}}}{n-2}}$$

Also, by substitution, the standard error of b ($S.E._{by \cdot x}$) is obtained by the formulae:

$$S.E._{by \cdot x} = \frac{S.D.y.x.}{C.I._x \sqrt{Sfd^2_x - \frac{(Sfd_x)^2}{n}}}$$

By using the values taken from the accompanying chart the modifications above may appear involved, but when the appropriate values are substituted in the equations the simplicity of the method becomes apparent.—E. JAMES, *Department of Agronomy, University* of Georgia, Athens, Ga.

Book Reviews

VEGETABLE GROWING

By J. S. Shoemaker. New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Limited. 506 pages, illus., 1947. $4.50.

THE author has for many years been concerned with the problems pertaining to the teaching of vegetable growing and has gained an appreciation of the difficulties encountered in such teaching. It is granted that the student should be versed in related subjects, such as soils, plant pathology, entomology, plant physiology, genetics, etc., however, the prime objective of a course in vegetable growing is not to teach these subjects as such but to relate them to vegetable production. The author has taken this point into consideration.

Vegetable seed production has become an important industry and improved methods of producing superior varieties should be the aim of seed producers. It is appropriate that the introductory chapter of the book should consider this phase of vegetable growing. A greater use of illustrations would be desirable. The book for the most part is well written, and should prove to be of value to the teacher and to the student. Vegetable growers and others who are interested in vegetable growing will no doubt find this book a valuable reference.—M. L. ODLAND.

TOMORROWS' FOOD: THE COMING REVOLUTION IN NUTRITION

By James Rorty and N. Philip Norman. Foreword by Stuart Chase. New York: Prentice-Hall, Inc. XIV +258 pages. 1947. $3.50.

THIS is an excellent and easy to read presentation, particularly from the layman's point of view, of some of the problems in and prospects for the production, processing, and marketing of a nutritionally superior food supply. The expert who is alert to the value of a favorable public opinion of his work will not be critical of the use of journalistic methods for accomplishing this.

The chapter on the late Dr. H. W. Wiley and his work is particularly pleasing in that it will present this great apostle of wholesome food to a new generation of readers. The authors have culled scientific reports of all kinds to present some rather startling facts. Thus, they state that one fourth of the first million draftees was rejected because of defective teeth, and they quote authorities to the effect that the four major deficiencies of the American diet, calcium, riboflavin, ascorbic acid, and thiamin, appear to be closely related to the major causes of draft rejections.

The authors examine with a reasonably critical mind Faulkner, Sir Albert Howard, and others. They point out that an important contribution of these men was to raise "the blood pressure of orthodox agronomists". The chapter, "Research Magnificent", which deals with the work of the U. S. Plant, Soil, and Nutrition Laboratory is in this reviewer's judgment only one example of good reporting of research activities in this book.—KENNETH C. BEESON.

ELEMENTS OF SOIL CONSERVATION

By Hugh Hammond Bennett. New York: McGraw-Hill Book Co., Inc. X+406 pages, illus. 1947. $3.20.

THIS book, according to the author, "Seeks to brief for the student the more important aspects of the serious problem of soil wastage and methods of soil conservation." Seven of the 22 chapters deal with the causes, extent, rate, and effects of soil erosion; 7 with control measures applicable to crop and pasture land and stream banks; and 6 with important related topics such as water spreading, drainage, irrigation and management of woodlands and wildlife. The remaining two chapters describe the United States programs for soil conservation and farm planning.

Soil conservation practice is called "the youngest of the major agricultural sciences" by the author. He gives it credit not only for the benefits from direct erosion control measures, such as contour strip cropping or terracing, but also for those obtained from more efficient fertilization, tillage, and pasture management introduced as part of an over-all plan for a farm. The informed reader will be astonished to find that only seven lines (not containing the word "soils") are used to describe the activities and contributions of the U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering and that no mention is made of that Bureau's splendid research in soil science, fertilizers, irrigation, and dry-land farming.

"Elements of Soil Conservation" is general in character, dealing with broad principles of erosion control rather than specific recommendations for local areas or soil conditions. Several of the chapters on control measures are notably clear and informative. This book is a brief, well-illustrated review of the subject and will interest the general reader, beginning students in soil and crop sciences, and those seeking a broad acquaintance with principles and practices.—R. J. MUCKENHIRN.

Agronomic Affairs

CALL FOR SOILS PAPERS

DOCTOR F. L. Duley, President of the Soil Science Society of America, has issued a call for papers for the several Sections of the Society at the meeting to be held in Cincinnati in November.

Titles and abstracts of papers to be presented at that time should be in the hands of the Section chairman on or before September 1st. A list of the Section chairmen for 1947 will be found in the December, 1946, number of the JOURNAL.

STUDENT SECTION ESSAY CONTEST — A CORRECTION

IN the April issue of the JOURNAL the announcement of the Student Section Essay Contest for 1947 made the statement that Doctor M. A. McCall had donated $100 for use as cash prizes for the best papers. In reality this contribution of $100 was made jointly by Doctor McCall and the *Northwestern Miller* of which Mr. P. L. Dittemore is Technical Editor. The Society regrets this incorrect statement, and wishes to express its appreciation of the fine support given this project by both contributing parties.

CORRECTION OF COMMITTEE REPORT

AN error occurs in reference No. 135 in the report of the Committee on "A Summary of Genetic Studies in Hexaploid and Tetraploid Wheats", published in the December, 1946, number of the JOURNAL. The correct citation is as follows:

135. Neatby, K. W. A chlorophyll mutation in wheat. Jour. Heredity, 24:159-162. 1933.

NEWS ITEMS

P. B. DUNKLE, Superintendent of Texas Substation No. 6 at Denton for the past 25 years, died of a heart attack on May 25th. Among other contributions to the agriculture of the Southwest, Mr. Dunkle is credited with the distribution of Nortex oats, now widely grown in the southern states. More recently he had been engaged in work with pastures and legumes.

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IN A MOVE to coordinate the activities of the Ohio Agricultural Experiment Station at Wooster and the Ohio State University, the agronomy sections of the two institutions have been combined under the direction of Doctor Garth W. Volk, with headquarters in Columbus.

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"LOST HARVEST" is the title of a new educational sound film in natural color produced by the E. I. du Pont de Nemours & Company. It shows the problems of seed- and soil-borne diseases and science's efforts to control them through chemical seed treatment. Correspondence regarding the loan of the film should be addressed to L. L. Stirland, E. I. du Pont de Nemours & Company, Semesan Division, Wilmington 98, Delaware.

THE BOARD OF DIRECTORS of the National Lime Association has approved the continuation of a four-year research fellowship program at five state agricultural experiment stations, located in New York, New Jersey, Pennsylvania, Maryland, and Ohio on a broad study of liming problems. The first year's work of this program is now being concluded. At the conclusion of each year's work the state agronomists and the research fellows meet to discuss and compare their findings and plan their research work for the coming year. Doctor Garth W. Volk of the Ohio Agricultural Experiment Station will act as host of this summer's meeting.

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THE AMERICAN POTASH INSTITUTE has released another in the series of bibliographies of literature on potash as a plant nutrient. The latest contribution covers literature reviewed from September through December, 1940. The list has three sections, the first being alphabetically arranged by crops and subarranged by place and author. A second section is arranged by subject under potash and another under soils, each subarranged by place and author. Copies of the mimeographed publication may be obtained upon request to the Institute at 1155 Sixteenth Street, N. W., Washington 6, D. C., as long as the supply lasts.

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DOCTOR WILLIAM H. ROSS, retired Principal Chemist of the Division of Soils, Fertilizers, and Irrigation, U. S. Dept. of Agriculture, died in Washington, D. C., May 16, 1947, at the age of 71. Doctor Ross was a former member of the American Society of Agronomy and of the Soil Science Society of America.

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DOCTOR D. W. THORNE, Associate Professor of Agronomy, Utah State Agricultural College, will become Head of the Department of Agronomy July 1 on the retirement of DOCTOR R. J. EVANS. Doctor Evans has been Head of the Department since 1930. He will continue his research work on alfalfa. Doctor Thorne took his B. S. degree at Utah State College and his graduate work at Iowa State College. He was on the faculty at Iowa State College, University of Wisconsin, and Texas A. and M. College before coming to Utah State College in 1939.